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USDA Forest Service Research Paper SE-129 May 1975

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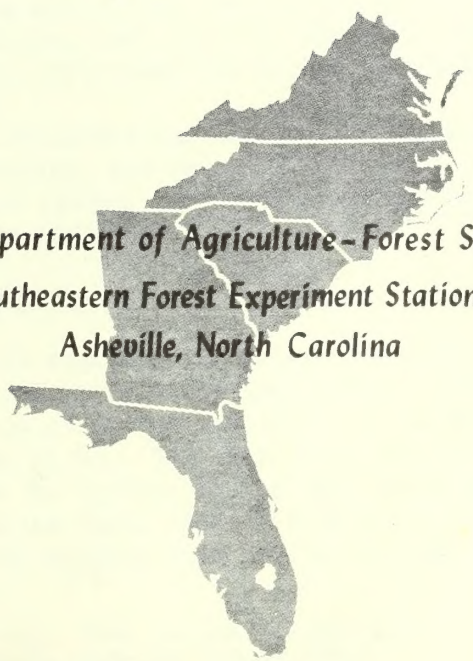

U.S. Department of Agriculture–Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Soil and Tree Responses to Intensive Culture in a Slash Pine Clonal Orchard: 12th-Year Results

by

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Where product values are high, forest trees are grown under intensive cultural regimes. Pine seed orchards (Bengtson and Goddard 1967), black walnut plantations (White 1969), Christmas tree farms (Rudolph 1972), and many general timber stands (Hagner et al. 1966; Anderson 1969; Pritchett and Hanna 1969) employ one or more cultural practices, including cultivation, irrigation, fertilization, and the control of weeds, diseases, and insects. Little is known about the long-term effects of such environmental manipulations on the soil.

This Paper discusses the effects of intensive culture (fertilization, irrigation, disking, and cover cropping) on soil chemical changes and associated tree growth in a slash pine (Pinus elliottii Engelm.) clonal orchard from 1960 to 1972.

EXPERIMENTAL DESIGN AND TREATMENTS

The study area was located in northeast Florida on a moderately well-drained soil formerly under cultivation. The soil is a Klej fine sand which consists of 92 percent sand, 5 percent silt, and 3 percent clay in the surface 15 cm. The fine sand continues to a depth of 2 m with little change in texture and a low moisture-holding capacity throughout. The mean water table is at 2 m, with short-term fluctuations (2 to 10 weeks) ranging from 1 to 2.2 m below the soil surface.

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The study was installed in 1957 and 1958 in a split-plot 2^3 factorial design with three replicates. Cultural treatments, begun in 1960, were as follows:

Irrigation (split-plot)

A. No addition to the average 132 cm of rainfall per year.

B. Irrigation to provide at least 5 cm of total water (rainfall plus irrigation) per week from March through November and at least 2.5 cm per week from December through February. Irrigation water came from a deep well and was distributed through an above-ground sprinkling system with rotating sprinkler heads. Table 1 shows rainfall and irrigation totals for the 12 years of treatment.

Table 1.--Total rainfall and irrigation on the study area from 1960 through 1972

Year	Rainfall	Irrigation	Total
	cm		
1960	128.27	40.64	168.91
1961	106.73	63.50	170.23
1962	95.35	109.22	204.57
1963	124.92	104.14	229.06
1964	207.60	35.56	243.16
1965	136.40	5.08	141.48
1966	176.05	50.80	226.85
1967	100.94	121.92	222.86
1968	100.76	108.71	209.47
1969	134.90	102.62	237.52
1970	141.50	110.74	252.24
1971	127.08	117.35	244.43
1972	133.48	124.97	258.45

Fertilization

A. No fertilizer.

B. Uramite (38 percent N) was hand broadcast around each tree (to a radius of 1.5 m) at the rate of 90 g of N/tree in April 1960 and 140 g/tree in April 1961; superphosphate (20 percent $P_2 0_5$) was broadcast over the entire plot at 56 kg of P/ha in April 1962; ammonium nitrate was spread at 168 kg of N/ha, both in the spring of 1964 and in May 1967.

Soil Cover

A. Disking to a depth of 12 cm four times annually until 1965 but only twice annually in subsequent years. Plots were disked in two directions to within 0.4 m of each tree.

B. A cover crop of hairy indigo (Indigofera hirsuta L.) was planted and mowed once annually until 1966. The legumes were completely shaded out by 1966, and the plots were subsequently mowed twice annually.

There were no untreated control plots; comparisons were made among the factorial combinations of treatments.

A set of 24 ramets (1 from each of 24 clones) comprised a plot for the cultural treatments. The plots were separated by one or two rows of commercial seedlings, and all trees were planted at 6- by 6-m spacing. Cultural treatments were begun in 1960 when the rooted cuttings were 2 to 3 years old. Reports of tree growth as related to cultural treatments and clonal variation have previously been reported (Bengtson 1969; Schultz 1969, 1972a, 1972b).

Soil samples were taken from each of the 24 plots in December of 1959 (just prior to the beginning of treatments), January 1963, May 1965, and in January of 1967, 1969, and 1972. Twenty random subsamples taken over the entire plot were combined into each sample. Subsamples were taken with a sampling tube from the 0- to 15-cm soil depth in 1960 and 1963 and from the 0- to 15-cm and 15- to 30-cm depths in 1965 to 1972.

Composite soil samples were air dried, sifted through a 20-mesh sieve, thoroughly mixed, and subsampled for analyses. Soil pH was determined from a slurry of 1 part soil and 2 parts water. Organic matter content of the soil was obtained by dry ashing duplicate 20-g samples at 700° C for 1 hour. The loss in weight on ignition was computed as a percentage of overdry weight of the sample.

Total nitrogen (N) was determined by macro-Kjeldahl analyses. Readily soluble phosphorus (P) was extracted with a solution of 0.1 $\underline{N}$ HCl and 0.03 $\underline{N}$ NH_4F at a 1:10 soil ratio for 5 minutes. Exchangeable potassium (K), calcium (Ca), and magnesium (Mg) in the soil were extracted with neutral $\underline{N}$ ammonium acetate and analyzed by flame emission or atomic absorption.

RESULTS

Soil analyses in 1959, one year prior to the initiation of cultural treatments, showed no soil differences between the plots subsequently irrigated and those left unirrigated. By 1963, however, Mg and pH were significantly greater in the 0- to 15-cm layer of the irrigated plots than in that of the unirrigated plots, and from 1965 through 1972 Ca, as well as Mg and pH, were significantly greater in the former (table 2). Irrigation also significantly increased Mg and pH from 1965 through 1972 and Ca from 1969 through 1972 in the 15- to 30-cm soil layer (table 3).

Fertilization decreased soil pH about 0.2 units in both the 0- to 15-cm and 15- to 30-cm layers from 1965 through 1972 (tables 2 and 3). Although fertilization significantly increased K in the 15- to 30-cm layer in 1972, the difference was only 1 p/m and probably not biologically meaningful.

Table 2.--Main treatment effects of intensive culture on various soil properties in the 0- to 15-cm soil layer on the study area

Soil property	Year	Irrigation	No irrigation	Fertilization	No fertilization	Cover cropping	Disking
Organic matter (percent)	1959	1.4	1.4	1.4	1.4	1.4	1.4
	1963	1.5	1.7	1.6	1.6	1.7*	1.5*
	1965	1.4	1.6	1.5	1.6	1.7**	1.3**
	1967	1.2	1.4	1.2	1.3	1.4	1.2
	1969	1.2	1.4	1.2	1.3	1.4*	1.2*
	1972	1.4	1.5	1.4	1.5	1.5	1.4
N (p/m)	1959	290	321	305	307	309	303
	1963	302	335	317	319	366*	270*
	1965	384	375	385	374	451**	308**
	1967	306	333	315	324	370**	268**
	1969	295	329	313	311	363**	261**
	1972	316	294	309	301	345**	265**
K (p/m)	1959	16	18	17	17	17	17
	1963	17	19	17	18	21*	15*
	1965	10	12	10	12	14**	9**
	1967	6	6	6	6	6*	5*
	1969	6	6	6	6	6	6
	1972	7*	6*	6	6	7	6
Ca (p/m)	1959	406	382	388	400	391	397
	1963	497	354	402	450	468	383
	1965	658*	370*	473	555	575	453
	1967	505*	298*	366	437	448	355
	1969	520*	282*	364	438	442	360
	1972	584**	272**	393	463	484*	372*
Mg (p/m)	1959	42	34	38	39	36	41
	1963	92*	32*	62	63	68	56
	1965	90**	28**	54	64	67*	50*
	1967	75**	20**	45	50	52*	43*
	1969	91**	20**	53	58	62*	49*
	1972	100**	19**	59	60	67*	52*
pH (units)	1959	5.7	5.6	5.7	5.7	5.7	5.7
	1963	7.1*	5.9*	6.4	6.6	6.5	6.5
	1965	6.9**	5.7**	6.2*	6.4*	6.3	6.3
	1967	7.1**	5.9**	6.4*	6.6*	6.6*	6.4*
	1969	7.5**	5.7**	6.5*	6.7*	6.6	6.6
	1972	7.6**	5.9**	6.6*	6.8*	6.8*	6.6*

*Designates significant difference between paired treatments at the 0.05 level.
**Designates significant difference between paired treatments at the 0.01 level.

Table 3.--Main treatment effects of intensive culture on various soil properties in the 15- to 30-cm soil layer on the study area

Soil property	Year	Irrigation	No irrigation	Fertilization	No fertilization	Cover cropping	Disking
Organic matter (percent)	1965	1.0	1.3	1.1	1.2	1.1	1.2
	1967	0.8	1.1	0.9	1.0	1.0	0.9
	1969	0.8	1.0	0.9	0.9	0.9	0.9
	1972	1.0	1.1	1.0	1.0	1.0	1.0
N (p/m)	1965	224	246	246	225	231	240
	1967	197	236	205	228	231	202
	1969	170	215	199	187	195	191
	1972	165	202	188	180	185	183
K (p/m)	1965	6	6	6	6	6	5
	1967	3	3	4	3	4	3
	1969	3	3	3	3	4	3
	1972	4	3	4**	3**	4	4
Ca (p/m)	1965	452	360	381	431	396	416
	1967	349	255	276	328	299	304
	1969	367*	236*	283	319	294	308
	1972	426*	266*	307	385	365	327
Mg (p/m)	1965	70**	19**	40	49	44	45
	1967	63**	13**	38	38	40	35
	1969	64**	12**	35	40	37	38
	1972	71**	12**	41	43	42	42
pH (units)	1965	6.8**	5.8**	6.2*	6.5*	6.3	6.3
	1967	7.1**	6.1**	6.6	6.6	6.6	6.6
	1969	7.3**	5.9**	6.5*	6.7*	6.6	6.6
	1972	7.6**	6.3**	6.8*	7.1*	7.0	6.9

*Designates significant difference between paired treatments at the 0.05 level.
**Designates significant difference between paired treatments at the 0.01 level.

There was a gradual decline in soil N in the 15- to 30-cm layer regardless of treatment (table 3). This change can be attributed to trees exploiting this depth as the root systems developed (Fisher and Stone 1969; Wells and Jorgensen 1974).

The surface cover (disking vs. leguminous cover crop) had a significant effect only in the 0- to 15-cm soil layer. Cover-cropped plots had significantly more soil N than disked plots by 1963, and the difference continued through 1972 (table 2). The greatest difference in soil N (143 p/m) occurred in 1965. By 1966, the legume cover was shaded out by trees, and differences in soil N on cover-cropped and disked plots gradually decreased to 80 p/m in 1972.

When compared with disking, cover cropping also significantly increased organic matter in the surface 15 cm of the soil (table 2). The difference reached a maximum of 0.4 percent in 1965--coinciding with the maximum difference in soil N. By 1972, organic matter on cover-cropped plots averaged 0.1 percent greater than on disked plots, a non-significant difference.

Readily soluble soil P ranged between 100 and 200 p/m throughout the 12 years of treatment. Ten p/m is generally regarded as adequate for tree growth on Coastal Plain soils. No treatments significantly altered soil P during the study.

Prior to treatment, exchangeable K in the surface 15 cm of the soil ranged from 14 to 20 p/m and averaged 17 p/m. Cover-cropped plots had significantly more K in the 0- to 15-cm soil layer from 1963 to 1967 than did disked plots (table 2). Potassium in the surface 15 cm of the soil dropped sharply from 1965 to 1967. The K levels in the 15- to 30-cm layer ranged from 5 to 6 p/m in 1965 but had decreased to 3 to 4 p/m by 1967 (table 3).

Irrigation significantly interacted with fertilization to alter the Ca, Mg, and pH levels at depths of 0 to 15 cm and Ca and pH at depths of 15 to 30 cm throughout the study period (table 4). In each layer, the combination of fertilization and no irrigation produced the lowest nutrient or pH level. The fact that this interaction was observed for Ca and pH in 1959, prior to treatment, strongly suggests that this condition is not entirely the result of cultural treatments.

Irrigation also interacted with fertilization to significantly affect organic matter content in the surface 15 cm in 1972 (table 4). Plots without either irrigation or fertilization had the highest organic matter content, while those irrigated but unfertilized had the lowest.

Table 4.--Interactions between irrigation and fertilization on the study area

Soil property	Year	Irrigation		No irrigation	
		Fertilization	No fertilization	Fertilization	No fertilization
0- TO 15-CM LAYER					
Organic matter (percent)	1972	1.5*	1.3*	1.4	1.7
Ca (p/m)	1959	475**	337**	301	463
	1963	545*	450*	259	449
	1965	712**	604**	234	506
	1967	536*	474*	196	401
	1969	548*	492*	180	384
	1972	614*	555*	173	371
Mg (p/m)	1963	99*	85*	25	40
	1965	91*	88*	16	39
	1972	105*	94*	13	26
pH (units)	1959	5.9*	5.6**	5.5	5.8
	1965	6.9**	6.9**	5.4	6.0
	1967	7.1*	7.1*	5.6	6.1
15- TO 30-CM LAYER					
Ca (p/m)	1965	515*	389*	246	473
	1967	368*	330*	184	326
	1972	456*	395*	158	374
pH (units)	1967	7.2*	7.1*	5.9	6.2
	1969	7.3*	7.3*	5.7	6.2
	1972	7.6**	7.6**	6.0	6.6

*Designates significant difference between paired treatments at the 0.05 level.
**Designates significant difference between paired treatments at the 0.01 level.

DISCUSSION

Intensive culture imposed large changes in soil pH, N, Ca, Mg, and moisture availability. These changes did not alter tree growth at age 4 (Bengtson 1969) but had significantly changed growth rate by age 9 (Schultz 1969). Although 12 years of irrigation increased pH from 5.7 to 7.6, it did not reduce apparent tree vigor or average tree size. However, irrigation increased growth the first 7 years and possibly decreased growth the last 5 years. At age 9 (1967), irrigated trees had 10 percent more merchantable volume than unirrigated trees (Schultz 1969). But at age 14 (January 1972), merchantable volume per tree was 0.35 m^3 for both irrigated and unirrigated treatments.[2] The fact that irrigation increased pH from 7.1 to 7.6 between 1967 and 1972 and unirrigated trees grew faster than those irrigated during the same period suggests that the high soil reaction may have affected tree growth. Rooting below the surface calcareous zone probably accounts for the relatively good growth of trees even though the surface pH was alkaline. The rooting depth of trees at age 11 in this plantation was over 3 m (Schultz 1972b), and the pH was approximately 7.3 at 1 m and 7.0 at 2 m below the soil surface.

Irrigation water used in this plantation came from a limestone aquifer 104 m below the soil surface. When treatment began in 1960, the water was pH 8.1 and contained 8.4 p/m Ca and 13 p/m Mg. At the

[2]Unpublished data on file at the Southeastern Forest Experiment Station, Naval Stores and Timber Production Laboratory, Olustee, Florida.

end of 1972, the water was pH 7.9 and contained 35 p/m Ca and 16 p/m Mg. Results suggest that soil alkalinity will continue to increase slowly on irrigated plots even though litter decomposition is probably counteracting some of the effects of irrigation. Further study is required to determine the nature of problems induced by increasing soil alkalinity and to develop methods to avoid or correct the alkaline condition.

In an attempt to relate the sudden drop of soil K in 1967 to tree nutrition, needle samples were taken from selected trees in December 1972 and analyzed for K. Percentage of foliar K ranged from 0.25 to 0.36 among the various treatments. The lowest level (0.18 percent K) was found in unirrigated plots. Both the foliar and soil analyses indicate a declining K status and deficiency conditions.

Cover cropping with hairy indigo apparently increased soil N by more than 300 kg/ha during the 5 years that the legume thrived between the rows of young pines. Once the legumes were shaded out, soil N quickly decreased.

Fertilization with N in 1960, 1961, 1964, and 1967 did not increase soil N during subsequent sampling, suggesting that this element was quickly utilized by the vegetation or leached below the 30-cm depth. However, with the procedure used for soil sampling, effects of the 1960 and 1961 fertilization may have been diluted because some of the subsamples were collected more than 1.5 m from the plot trees.

The combination of cover cropping and irrigation increased merchantable tree volume over cover cropping without irrigation by 15 percent (0.05 m^3 per tree) at age 9, 7 percent (0.04 m^3) at age 12, and 3 percent (0.02 m^3) at age 14. Plots which were disked and irrigated or disked but not irrigated had intermediate growth rates. The differences in volume growth at ages 9 and 12 were statistically significant at the 0.01 level of probability (Schultz 1969, 1972a). From age 12 to 14 years, growth increment on plots which were cover cropped but not irrigated was significantly greater than growth under other treatment combinations. These results suggest that early N production by legumes which were not irrigated may have been tied up during the growing seasons in the developing cover crop. Decomposition of organic matter after the legumes were shaded out under the pines apparently released a sufficient amount of N to stimulate subsequent tree growth.

While the results of this study are valuable as a case history of the effects of certain cultural factors on important soil characteristics in a fairly representative seed orchard, they cannot be taken as predictive of what may occur on other soils which differ significantly in physical and chemical characteristics. Nevertheless, it should be of general interest that applications of nitrogen and phosphorus fertilizer in this study had less effect on key soil properties and tree growth than did leguminous cover cropping. Furthermore, the most pronounced and potentially most important effect of intensive culture was not a direct

result of fertilizer, cover cropping, or irrigation, but the indirect or "side" effect of irrigation in markedly changing the base status of the soil and increasing its pH. Clearly, then, one of the important decisions facing seed orchard managers debating the merits of irrigation is the quality of the water available and its expected effects upon the soil and tree crop in question.

LITERATURE CITED

Anderson, H. W.
1969. Douglas-fir region aerial fertilization makes strides in a brief span of years. For. Ind. 96(12): 30-37.

Bengtson, George W.
1969. Growth and flowering of clones of slash pine under intensive culture: early results. U. S. D. A. For. Serv. Res. Pap. SE-46, 9 p. Southeast. For. Exp. Stn., Asheville, N. C.

Bengtson, George W., and Ray E. Goddard
1967. Establishment, culture and protection of slash and loblolly pine seed orchards: some tentative recommendations. U. S. For. Serv., S&PF, Southeast. Area, For. Nurserymen Conf. Proc. 1966: 47-63.

Fisher, R. F., and E. L. Stone
1969. Increased availability of nitrogen and phosphorus in the root zone of conifers. Soil Sci. Soc. Am. Proc. 33: 955-961.

Hagner, S., B. Johansson, J. Saraste, and A. Ahgren
1966. Timber production by forest fertilization. Sver. Skogsvardsfoeren. Forb. Tidskr. 64(2): 103-171.

Pritchett, W. L., and H. Hanna
1969. Results to date, potential gains in Southeast generate cautions optimism. For. Ind. 96(11): 26-28.

Rudolph, V. J.
1972. Costs and returns in Christmas tree management. Mich. State Univ. Agric. Exp. Stn. Res. Rep. 155, 23 p.

Schultz, Robert P.
1969. What is being learned from intensive management of slash pine. For. Farmer 28(6): 8-9, 16.

Schultz, Robert P.
1972a. Inherent vigor influences growth of slash pine more than intensive cultural treatments. Silvae Genet. 21: 26-28.

Schultz, Robert P.
1972b. Root development of intensively cultivated slash pine. Soil Sci. Soc. Am. Proc. 36: 158-162.

Wells, C. G., and J. R. Jorgensen
1975. Nutrient cycling in loblolly pine plantations, p. 137-158. In Forest soils and forest land management. Fourth North Am. For. Soils Conf. Proc. 1973. Laval Univ., Quebec, Can.

White, D. P.
1969. Research and development of forest fertilization in northeast and midwest. For. Ind. 96(10): 29-31.

Schultz, Robert P., Carol G. Wells, and George W. Bengtson
1975. Soil and tree responses to intensive culture in a slash pine clonal orchard: 12th-year results. USDA For. Serv. Res. Pap. SE-129, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

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The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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USDA Forest Service Research Paper SE-130 May 1975

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INTRODUCTION

In 1971, Jorgensen and Wells reported average nitrogen (N_2) fixation of 949 g of N/ha/yr on annually burned plots in a 56-year-old loblolly pine (Pinus taeda L.) stand on the Westvaco Experimental Forest near Georgetown, South Carolina, but only 44 g on unburned plots. No other reports on quantitative N_2 fixation in forest Coastal Plain soils have been made thus far.

This report describes and presents the results of four groups of experiments designed to obtain information on some facets of N_2 fixation. The objectives of these experiments were to: (1) Determine N_2 fixation potential for a number of Coastal Plain sites, (2) estimate some of the variation in fixation within a limited area, (3) measure the effects of moisture, energy materials, and some inorganic nutrients on fixation, and (4) identify the organisms responsible for fixation. The general methods used in all experiments are described in the methods and materials section. Procedures specific for individual experiments are given under separate headings and are followed by the results and discussion which apply to that experiment.

METHODS AND MATERIALS

Measurement of N_2 Fixation

In 1966, Schöllhorn and Burris, and Dilworth noted the inhibition of N_2 fixation by acetylene. In the same year Koch and Evans showed that acetylene (C_2H_2) was quantitatively reduced to ethylene (C_2H_4) by the same system responsible for the fixation of N_2. These initial discoveries were quickly developed by several investigators into a system for the qualitative and semi-quantitative estimation of N_2 fixation by substituting the measurement of acetylene reduced to ethylene for that of N_2 fixed. The acetylene reduction method was adopted for the present studies because it provided the sensitive, simple procedure that could be applied to the large number of samples needed to estimate the low fixation rates that were expected to occur in forest soils. The procedure was reported by Hardy et al. (1968) as 103 times more sensitive than using ^{15}N to measure fixation and 106 times more sensitive than measuring nitrogen changes by Kjeldahl analysis.

N-fixation potential was measured on cores 37 mm in diameter that included the forest floor and approximately the upper 25 mm of mineral soil. The cores were placed in 135 ml babyfood jars which served as chambers to control the atmosphere and moisture of the soil sample. Jar caps were fitted with serum stoppers to provide access to the jars with syringes for the addition or removal of gases and liquids. Atmospheric volume in the jars averaged 115 ml after deducting the approximate volume of the soil samples. Samples were stored at room temperature for approximately 2 days before N_2 fixation tests were begun.

To test soils for N_2-fixation potential by the acetylene reduction method, the N_2 in the sample atmosphere was first removed by evacuating and refilling each jar five times with a mixture of 22.2 percent O_2 and 415 p/m CO_2 in Ar. After the last filling, 20 ml of the gas mixture were removed and replaced with 25 ml of acetylene to make about a 20-percent acetylene atmosphere. In all experiments, blank jars with no soil were prepared.

In most cases, after an initial 24-hour incubation period at approximately 30° C, the amount of ethylene produced by the reduction of acetylene was measured on a gas chromatograph. Details of the procedure are given by Jorgensen and Wells (1971). The quantity of ethylene produced was converted to an equivalent amount of N_2 fixed per hectare to the depth represented by soil samples. Fixation which may occur below this depth was not included in estimates. The theoretical value of 1.5 moles of C_2H_4 equivalent to 1 g atomic weight of N was used in all caculations. This conversion factor may overestimate actual fixation by several times, depending on the environmental conditions. Several soil samples were tested for endogenous ethylene without the addition of acetylene, but no significant amounts of ethylene were found.

Time of Sampling and Site Descriptions

On September 23 and 24, 1970, soil cores were taken from five very poorly to moderately well-drained upland Coastal Plain sites between Charleston and Andrews, S.C., and from three swamps near Huger, S.C. Two of the upland Coastal Plain sites were also sampled in June 1970. Brief descriptions of the sites follow:

Recently Bedded Area

The tract had been prepared for planting by bedding and by fertilizing with 56 kg/ha of P within the preceding year. Soil cores were collected from the tops and bottoms of furrows, and on undisturbed areas to determine if site preparation had influenced N-fixation distribution. Undisturbed surface soil was dark-colored and had a fine loamy or clayey texture. In the bedded area surface soil ranged from coarse sand to fine clay. Most of the bedded ground was devoid of vegetation; the undisturbed area had a growth of annual weeds and woody sprouts.

Thirteen-Year-Old Slash Pine Plantation

This savannah area of Bayboro loam received 56 kg/ha of P and 112 kg/ha of N in 1968, 10 years after planting. The stand was open and the ground covered with grass. Soil samples were obtained from fertilized and unfertilized portions of the plantation.

Four-Year-Old Loblolly Pine Plantation

Loblolly pine had been planted on a bedded area of Bayboro loam adjacent to the 13-year-old slash pine plantation. At the time of planting, 56 kg/ha of P had been applied. Fertilized trees were much larger than those not receiving fertilizer. Soil cores were collected from the tops and between the beds from fertilized and unfertilized areas.

Burning Treatment Plots 6, 18, and 21 on the Westvaco and Santee Experimental Forests

The annual summer burn and unburned areas of a prescribed burning study installed in 1946 (Lotti et al. 1960) were utilized. Soil core samples were collected in June 1970, a few days before burning, and again in September 1970. Soils were poorly and very poorly drained loams and sandy loams of the Bladen and related series. Overstory consisted of loblolly pine between 55 and 65 years old. Understory vegetation varied from a thick growth of small hardwood trees and shrubs on unburned areas to little or no understory vegetation except for grass on plots annually burned in the summer. Site index of loblolly pine was about 95 on the Santee and 90 on the Westvaco.

Nicholson Creek, Santee River, and Bluebird Swamps

Nicholson Creek Swamp is a tidal freshwater overflow area with a dense hardwood overstory and little or no understory vegetation; the forest floor consisted principally of wet, decaying hardwood leaves. Santee River Swamp is a first bottom overflow area occupied by a dense, vigorous stand of young swamp hardwoods and cypress; the forest floor also consists of wet, rotting hardwood leaves. Bluebird Swamp is a headwater swamp that had been recently logged; residual vegetation consisted of a sparse stand of cull and small trees, hardwood sprouts, shrubs, and a dense growth of grassy and herbaceous plants.

PROCEDURES, RESULTS, AND DISCUSSION OF INDIVIDUAL EXPERIMENTS

N_2-Fixation Potential in Soil

Experimental Procedures

Samples were collected in June at the Westvaco and Santee Experimental Forests and at all sites in September. Special care was taken to obtain samples collected in September from areas of the Westvaco and Santee Forests burned plots that had been sampled in June. Test procedures to measure N_2-fixation potential were carried out as described. Moisture in soil cores was adjusted to approximate field capacity to reduce variation in fixation.

Results and Discussion

Upland forest soils sampled in September had a low, relatively uniform, level of N_2 fixation. For all upland areas sampled, average fixation was 0.51 g of N/ha/day (table 1). Cores taken from burned areas of the Santee and Westvaco Experimental Forests fixed an average of 0.60 g of N/ha/day compared to 1.99 g in cores taken in June before burning. The difference in N_2 fixation in June and September may be attributed, in part, to seasonal effects on N_2 fixation, the several-month effects of the prescribed burn made shortly after the June sampling, and to highly variable fixation accompanied by a small number of samples. The combined seasonal-burning effect on fixation was significant at the 5-percent level only on plot 6 at the Westvaco Experimental Forest where fixation was 3.107 g of N/ha/day in June, compared to 0.673 g in September ($T = 2.343$ with 25 df). A significant difference at the 10-percent level in N_2 fixation for June and September, respectively, was obtained on Westvaco plot 18: 1.841 g vs. 0.675 g ($T = 1.741$ with 25 df). There was no significant difference on Santee plot 21 between the 0.810 g of N/ha/day fixed in June and 0.539 g of nitrogen fixed in September.

Table 1.--Nitrogen fixation in the Coastal Plain

Site	Month of collection	Cores tested	N-fixation
		Number	g N fixed/ha/day
Upland sites			
4-year-old loblolly plantation	September	20	0.31
13-year-old slash plantation	September	12	.31
Recently bedded area	September	17	.48
Westvaco plots 6 and 18 before burning	June	31	2.45
Westvaco plots 6 and 18 after burning	September	23	.63
Westvaco unburned control	September	6	.90
Santee plot 21 before burning	June	12	.81
Santee plot 21 after burning	September	9	.54
Santee unburned control	September	3	.92
Swamp soils			
Nicholson Creek	September	3	25.3
Santee River	September	4	7.3
Bluebird Swamp	September	3	38.2

Late summer is a time when fixation potential may be at a minimum, at least in upland soils. During the summer these soils have passed through a series of wetting and drying cycles in which drying has intensified with time. Since N_2 fixation in these acid soils is primarily an anaerobic process, drying will reduce the activity of anaerobic organisms by increasing soil oxygen content and reducing moisture. During the time of reduced activity, spores form to produce a potential for biological N_2 fixation when the proper environmental conditons arise.

The primary source of energy for soil microorganisms is litterfall. Litter decomposition occurs most rapidly during the first year when needle weight is reduced by about one-third. This weight loss consists primarily of relatively simple carbohydrates--simple sugars, hemicellulose, and cellulose--compounds which Clostridium spp. can, by itself or in conjunction with other organisms, utilize as energy sources. Anaerobic organisms may utilize these compounds most rapidly in the spring when suitable combinations of temperature, moisture, and energy source are present. Cold water soluble materials, comprising 10 to 20 percent of the weight of leaf litter, are some of the more readily available energy sources. Daubenmire and Prusso (1963) have shown that about two-thirds of these materials from several pine and hardwood species are lost through decomposition over a 100-day period. Thus,

with most litter falling in October and November, the major portion of the simple compounds that provide energy will be utilized well before the advent of the next litterfall.

Throughfall, with carbohydrates leached from leaves or needles, is a second potential source of energy material. Unfortunately, we have little information on the carbohydrates in throughfall. Carlisle (1965) measured carbohydrates in oak throughfall and showed a decrease from the 67.8 kg/ha in August, when first measured, to 5.6 kg/ha in November when the last measurement was taken. He concluded that these soluble energy sources have a considerable influence on the biological processes of the upper soil horizons. If these carbohydrates are present in throughfall, they may contribute a substantial energy source to N-fixing bacteria, especially since they are present when soil is moist.

Prescribed burning reportedly increases nonsymbiotic N_2 fixation over that obtained from unburned areas (Jorgensen and Wells 1971). In the present study, however, samples collected in September from both experimental forests fixed 0.60 g of N/ha/day on burned areas and 0.91 g on unburned areas, a difference that was not significant. Why there was no difference in rates is not known, but no samples collected in September had high N_2 fixation rates, and high rates were found in June. The few samples from an area that are capable of a high fixation rate probably contribute the majority of N fixed nonsymbiotically on the entire area (Jorgensen and Wells 1971).

A high fixation potential can exist in soil under some conditions (table 1). Swamp soils generally had a high fixation rate, averaging nearly 22 g of N/ha/day. However, fixation in these soils was variable, with cores fixing from less than 1 g to nearly 44 g of N/ha/day. These soils are well suited for the growth of anaerobic bacteria. They possess abundant organic material supplied by both native vegetation and that transported to the site by water movement, and only under the most extreme drought conditions does moisture fall below field capacity.

Variability of N_2 Fixation Within and Between Areas

During an initial investigation (Jorgensen and Wells 1971), it was found that cores from some areas of a plot tended to have high fixation and from other areas low fixation, and that variation in fixation between areas was greater than fixation within areas. The present investigation was conducted to get more information relating to the tendency for N_2 fixation to be similar within a limited area. In addition, when cores were obtained from the field, observations were made to determine whether any obvious site characters--vegetation, litter, etc.--could be correlated with later N_2 fixation measurements.

Experimental Procedures

This investigation was restricted to three 0.09 ha plots that received the annual summer burning treatment. On June 15 and 16, 1970, just before the annual summer burns, three sample areas on plot 21 on the Santee Experimental Forest and four sample areas on each of plots 18 and 6 on the Westvaco Experimental Forest were located to measure N_2-fixation potential. Each sample area was about 0.36 m^2, regularly located in one-fourth of a plot. One core was taken from each quadrant of a sample area. A total of 44 samples were taken. After N fixation was measured, the cores were used in an experiment to show the effects of moisture and nutrients on fixation.

Cores were placed in jars and tested for N_2 fixation with moisture content as collected. Water was then added in two stages for testing at field capacity and with an excess of water. All incubation took place at approximately 30° C.

Results and Discussion

Multiple samples taken within an area of 0.36 m^2 and tested at the soil moisture content as collected had N_2-fixing capacities that were significantly related. The correlation coefficient obtained for the multiple samples within an area was 0.646, significant at the 1-percent level ($F = 8.29$ with 7 and 30 df). Average N_2 fixation rate for replications within an area ranged from 0.06 to 7.70 g/day. When soil sample moisture was increased to field capacity, significance dropped to the 10-percent level. This decrease was due primarily to an increase in the variation of N_2 fixation among replicates, although the average range for sample areas, 0.10 to 6.45 g of N_2 fixed/day, was similar to that obtained with no moisture addition. These tests confirmed the theory that rate of fixation on a large area (0.09 ha in this case) is not completely random, but that within the area, cluster samples with similar rates of fixation may be obtained.

The variation between small areas did not seem associated with soil texture, measured pH, and organic matter as indicated by soil color, or micro-relief. Nutrient contents or organic constituents of individual samples were not investigated, however, and their distribution patterns may have influenced fixation.

Effects of Moisture, Mineral Elements, and Energy Material on N_2-Fixation

Experimental Procedure

The variables of moisture and the amendments of glucose and mineral elements were investigated to determine their effects on N_2 fixation.

The 44 cores from the Westvaco and Santee Experimental Forests, initially used for the measurement of the variability in N_2 fixation, were, in this experiment, first used to show the effects of moisture on N_2 fixation, and following that the effects of moisture and nutrient amendments on N fixation. A second set of samples, 16 cores from fertilized and 16 from unfertilized sections of the 4-year-old loblolly and 13-year-old slash plantations, was used only for measuring the effects of amendments on N_2 fixation.

Nitrogen fixation was measured under three soil moisture levels. The first measure was with soil moisture as it was at the time of collection, below field capacity but above the wilting point. A 64-hour incubation period was used with this treatment and two measurements of fixation were made. Following this initial treatment, 5 ml of water per sample were added to bring soil to approximately field capacity. Incubation with this treatment was for 24 hours with analysis for ethylene at the end of the period. A second addition of 5 to 8 ml of water to each jar then provided excess moisture. Incubation was continued and a final gas sample taken 24 hours later. At the excess moisture level, 36 of the 44 soil cores had 1 to 2 ml of water standing in the bottoms of their jars. The amount of acetylene reduced by each treatment was determined by subtracting that produced by the previous treatment from that present at the time of sampling. Fixation was then expressed as the g of N fixed/ha/day (24-hour period), with adjustment made for the actual time of incubation. Soils were incubated at approximately 30° C.

Glucose, an energy source, and the elements P, Mo, and Co were used to study their effect on N_2 fixation. Because cores had been used to measure N_2 fixation before this experiment, all cores were aerated for 3 weeks, during which time moisture level fell to a point between field capacity and wilting point. At this moisture content, cores were incubated with acetylene for 24 hours at 30° C and tested for fixation to establish a basis for any change in fixation that may occur attributable to amendments.

A glucose solution, 10 g/liter of tapwater, and a mineral solution containing 5 g K_2HPO_4, 0.1 g $Na_2Mo \cdot 2H_2O$, and 0.1 g $CoCl_2 \cdot 6H_2O$ in 1 liter of tapwater were prepared, autoclaved, and made up into three soil amendments:

Glucose (G):200 ml glucose solution + 50 ml H_2O

Mineral (M):50 ml mineral solution + 200 ml H_2O

Glucose + mineral (G + M): 200 ml glucose + 50 ml mineral solution.

The approximately 80 cores which had been tested without amendments were divided into four treatment groups: a control receiving only water, and three groups each receiving one of the soil amendment solutions. Eight ml of amendment or water were then added to each core

and the cores incubated for 24 hours, the atmosphere analyzed for ethylene, and the core then reincubated for an additional 48 hours. Mineral and glucose soil amendments were applied at rates equivalent to 14 kg of P and 640 kg of glucose/ha.

Results and Discussion

Level of soil moisture had a significant effect on N_2 fixation. Raising soil moisture to approximately field capacity increased the average level of N_2 fixation from 1.34 to 1.90 g/ha/day (table 2). This increase, based upon sample area averages and analyzed by t test, was significant at the 5-percent level. An excess of water, sufficient to have standing water in the bottom of the jar but not completely covering the soil, raised fixation from 1.90 to 3.15 g/ha/day. This increase was not, however, significant at the 5-percent level. About half of the samples increased the rate of ethylene production and the other half decreased it, although increases were much greater than decreases. Previous work (Jorgensen and Wells 1971) has shown a decrease in ethylene production with time, especially in samples which have little N_2-fixation potential, whereas soils with high fixation either increase or show little change. Thus, the excess moisture treatment was confounded with length of incubation and may not correctly reflect the effect of excess moisture. Ethylene production at each succeeding increase in moisture was highly correlated with previous production, although ethylene production decreased in four of 11 sample areas (table 2).

Table 2.--Variability of N_2 fixation in soil with an unaltered moisture content and the effects of increasing soil moisture content on N_2 fixation in soil from annual burn plots on the Santee and Westvaco Experimental Forests, by sample area

Treatment and location	Sample area	Moisture condition		
		Unaltered (as collected)	Field capacity	Excess
		- - - - - g N fixed/ha/day - - - - - -		
Annual burn, Santee, plot 21	1	0.08	0.24	0.20
	2	.56	2.10	4.92
	3	.06	.10	.10
Average		.23	.81	1.74
Annual burn, Westvaco, plot 6	1	7.70	6.45	20.57
	2	1.66	2.39	.99
	3	.87	2.72	3.00
	4	.33	.87	2.03
Average		2.64	3.11	6.65
Annual burn, Westvaco, plot 18	1	1.70	2.52	.59
	2	2.27	3.25	3.39
	3	.08	.30	0
	4	.56	1.11	.25
Average		1.15	1.80	1.06
Average*		1.34	1.91	3.15

*Average, all treatments and locations.

Phosphorus fertilization of field plots 2 or 3 years prior to sampling had little influence on the rate of N_2 fixation. Cores taken from fertilized plots fixed 0.27 g of N/ha/day, while cores from unfertilized plots fixed 0.35 g.

Glucose and glucose plus mineral amendments to soil in the laboratory had an important stimulating influence on fixation, whereas mineral amendments alone had no effect (fig. 1). Incubation with glucose for 24 hours increased fixation to 6 g/ha from less than 0.5 g of N/ha in nonamended soils. The combination of minerals and glucose tripled the fixation obtained with glucose alone in 24 hours. At the end of 72 hours of incubation, glucose amended soil had fixed approximately 150 g of N/ha and glucose plus mineral amended soil fixed nearly 350 g/ha. Additions of water or mineral solution had no effect on fixation, which decreased slightly as incubation time lengthened. The increase in fixation rate in glucose and glucose plus mineral amended soils over the entire 72-hour period was directly related to the increase that occurred during the first 24 hours.

In some instances addition of Co and Mo to soil have been essential for N_2 fixation. A series of experiments, details of which are not presented, was established to determine their necessity as soil amendments to promote N_2 fixation in soil. It was found that the incorporation of these elements with other soil amendments had no effect on fixation. Apparently the soil had a supply of these elements sufficient to satisfy N_2-fixation requirements. Thus, any increase in fixation associated with the mineral amendment was due to P, not Mo or Co.

Within 24 hours of adding nutrients to the soils, 69 percent of the cores amended with glucose, and 91 percent of the cores amended with glucose plus mineral responded with an increased N_2-fixation rate. This indicates N_2-fixing microorganisms were present in sufficient number or were able to increase their populations rapidly enough to compete with other soil microorganisms for readily available carbohydrates. These microorganisms were also able to compete for more than 24 hours after the soil was amended, as shown by the increased rate of fixation obtained at the 72-hour measurement. Lack of increase in fixation rate of soils receiving only minerals indicated that a sufficient energy source was not available.

The amount of N_2 fixed by anaerobic organisms has been reported to be approximately 2.15 mg of N/g of wheat straw or 2.4 mg of N/g of hemicellulose. In a soil-glucose system, C. pasteurianum fixed an average of 1.3 mg of N/g of glucose (Rice and Paul 1972). In the present study, N_2 fixation amounted to about 0.5 mg/g of glucose. This value is not necessarily low, however, since the N_2-fixing organisms must compete with the normal complement of soil microflora for the added glucose.

Although an energy source, as glucose, initially controls N_2 fixation, the interaction between glucose and phosphorus shows the importance of an adequate supply of both. Both energy sources and phosphorus

are necessary for the generation of adenosine triphosphate (ATP). ATP provides the energy for the reaction between molecular nitrogen and nitrogenase to produce ammonia which may be utilized by the micro-organism.

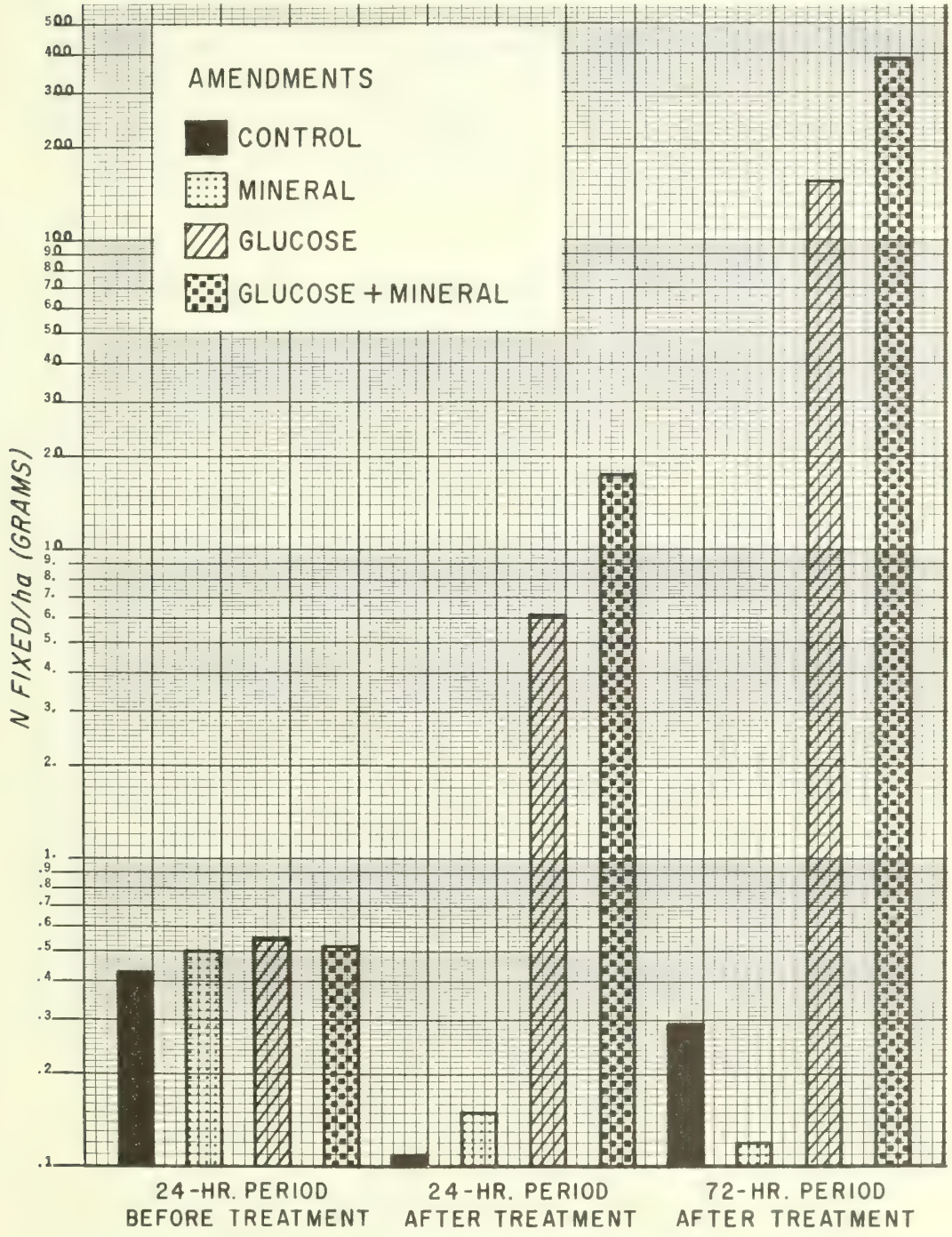

Figure 1.--Effects of amendments and length of incubation on N fixation.

Organisms Responsible for N_2 Fixation in Soil

Nonsymbiotic N_2 fixation in soil may be accomplished by bacteria, blue-green algae, and possibly the yeast Rhodotorula. Blue-green algae have the ability to fix important quantities of N_2 in specialized environments, such as rice paddies, deserts, and other soils that have a high pH and plentiful moisture for at least limited periods of time. A large and varied group of bacteria are able to fix N_2. This group includes both aerobic and anaerobic organisms, but N_2 fixation, even by aerobic organisms, is most efficient under reduced oxygen tension. Several of the genera of bacteria capable of N_2 fixation are Azotobacter, Bacillus, Clostridium, Desulfovibrio, Methanobacterium, and Pseudomonas.

Experimental Procedure

Soils from annually prescribed burned and unburned plots of the Westvaco Experimental Forest were examined for the presence of Azotobacter, Methanobacterium, and blue-green algae, all of which fix N_2. Five soil samples with a low N_2-fixation potential and seven samples with a high potential by N_2-fixation test procedures were used for the isolation of organisms.

Soils examined for the presence of anaerobic N-fixing bacteria included those from the Westvaco annual burn plots, the 4-year-old loblolly pine plantation, and the Santee River swamp. These soils had been used to study the effects of glucose, mineral, and glucose-mineral combinnations on N_2 fixation about a month earlier. Eighteen samples were examined.

Presence of blue-green algae was determined by using liquid and solid media, with and without a fixed nitrogen source, incubated under conditions developed by Allen and Stanier (1968). For each of the 12 soil samples, three tubes of nitrogen-free liquid media and two tubes of the fixed N_2-supplemented media, each containing 5 ml, were innoculated with 1 ml of 1:100 soil dilution. Three petri plates of solid media for each soil were innoculated with 1 ml of a 1:1,000 soil dilution. Tubes and plates were incubated at 35° C and 600 lx for 16 hours a day for 12 and 35 days, respectively.

Media developed by Brown et al. (1962) with glucose as a carbon source, and by Rice and Paul (1971) with mannitol as a carbon source were used to determine if aerobic N_2-fixing bacteria, primarily Azotobacter, were present. Each soil sample was replicated in triplicate with each medium with dilutions of 1:100 and 1:1,000. Plates were incubated 14 days at 25° C.

The population of N-fixing methane-oxidizing bacteria was measured by the method of Davis et al. (1964). Plates, in triplicate, were innoculated with 1:100 soil dilutions and incubated at room temperature for about a week in a 30-percent methane atmosphere.

Anaerobic N_2-fixing bacteria were isolated using Ross' medium modified by Jurgensen (1967) and further modified with 5 g/liter of potato dextrose agar replacing a potato extract, and increasing the 10 g of Ionagar to 14 g. Each of the 18 soil samples was planted in triplicate at dilutions of 1:1,000 and 1:10,000 and incubated under anaerobic conditions (a 95 percent N_2 - 5 percent CO_2 atmosphere). After 7 days of incubation at room temperature, colonies were counted and grouped into four catagories: (1) Gas producing, usually over 3 mm diameter, (2) non-gas producing over 3 mm in diameter, (3) non-gas producing 1-3 mm diameter, and (4) non-gas producing less than 1 mm diameter. Copious growth and gas production on a nitrogen-free media are two criteria for selecting bacteria capable of N_2 fixation.

Results and Discussion

No methane-oxidizing bacteria, aerobic bacteria, or important numbers of algae capable of reducing significant amounts of acetylene, the indication of potential N_2 fixation, were isolated.

Several algae were able to survive on the initial isolation media, but by the time a third transfer was made to nitrogen-free media all growth ceased. None of the algae isolated contained heterocysts or were blue-green species associated with N_2 fixation. Blue-green algae have been found to be important as a source of N_2 fixation where pH is approximately neutral or alkaline as in desert soils, rice paddies, or near limestone deposits. Granhall and Henriksson (1969) working in Sweden, failed to find any blue-green algae in soils below pH 5.0 and even up to pH 6.0 algal filaments with heterocysts were not abundant. They also found algal filaments with heterocysts occurred only rarely in 10 percent of the forest humus samples examined and not at all in the other 90 percent.

Several thousand aerobic organisms per gram of soil were able to grow on nitrogen-free media, with several times more growing on mannitol than on glucose agar. Forty-two aerobic colonies with small clear or large mucoid configurations were isolated and transferred to mannitol and glucose slants, but no isolates were found to reduce important amounts of acetylene. The large mucoid colonies were identified as Lipomyces, a yeast capable of growing at very low concentrations of organic or ionic nitrogen or able to remove ammonia from the atmosphere. The bacteria forming the small colonies were not identified.

At a dilution of 1:10,000, over 10^6 anaerobic bacteria per gram of soil were isolated. However, most of these formed colonies less than 3 mm in diameter and did not produce gas. Thirty-six hundred to 139,200 bacteria per gram of soil formed gas-producing mucoid colonies over 3 mm in diameter (table 3). These bacteria were assumed capable of N_2 fixation and are termed N_2-fixing organisms.

Table 3.--Number of gas-producing anaerobic organisms found in soils tested for N_2 fixation

Location	Organisms per gram of soil
	1,000
4-year-old loblolly plantation	26.7
Annual burn, Westvaco plot 6	4.2
Annual burn, Westvaco plot 18	7.2
Annual burn, Santee plot 21	3.6
Santee River Swamp	139.2

The number of N_2-fixing bacteria isolated appeared correlated with site wetness. In upland soils there was no correlation between the number of N_2-fixing bacteria isolated and N_2-fixation potential, or glucose, mineral, and glucose-mineral amendments. Of the soils examined, the largest number of N_2-fixing bacteria were obtained from the Santee River swamp samples, which had a high fixation potential of 7 g of N/ha/day (table 3). Rice and Paul (1972) found the number of Clostridium spp. isolated from soil follow very closely the acetylene reduction taking place at the time of isolation. In the present experiment, the poor relationship between the number of N_2-fixing organisms and N_2-fixation potential may have been caused by a several-day delay between fixation measurements and population sampling. Populations may have reflected the N_2-fixation potential of soil conditions at the time of sampling, rather than when N_2-fixation was measured. Work reported by Vlassak, Paul, and Harris (1973) on N_2 fixation in grassland soils also showed no relationship between fixation and total bacteria populations, or growth on nitrogen-free media.

The gas-producing anaerobic organisms growing on the N-free agar were rod-shaped, about 5 u long, and often had an endospore near one end. The organisms resemble Clostridium, although they could not be distinguished from Bacillus polymyxa as pictured and described by Jurgensen (1967). No attempts were made to complete identification of the bacteria based upon biochemical tests or their ability to grow under aerobic conditions, a basis for separating B. polymyxa from Clostridium.

SUMMARY AND CONCLUSIONS

Nitrogen fixation in soil samples collected in the early fall fell into two general categories: relatively low fixation of less than 1 kg/ha/yr in upland mineral soils and fixation of over 10 kg/ha/yr in the swamp soils. Samples taken in June before a prescribed burn had a N_2-fixation potential at least twofold greater than samples taken in September about 3 months after the burn.

Nitrogen fixation potential tends to stratify within small areas rather than have a random distribution. However, the cause of the stratification was not found. Within a site there was no obvious relationship of N_2 fixation to vegetation, litter, or microtopography. At the present time, only when site-to-site differences are great, as between swamp and upland, can correlations be made between N_2 fixation and the environment.

Soil water, nutrients, and organic materials interact to provide an environment suitable for N_2 fixation. Addition of an excess of water to soil below field capacity increased fixation from about 1 to 3 g of N fixed/ha/day. Amending a well-watered soil with minerals, primarily phosphorus, produced no increase in fixation; a glucose amendment increased fixation to approximately 6 g/ha/day from less than 0.5 g/day in unamended soil, but a combination of minerals and glucose tripled fixation of N obtained by glucose alone in the same period of time. Tripling incubation time to 72 hours increased fixation by about 20 times where glucose and glucose plus minerals were applied, but additional time had no effect on increasing N fixation in soils amended with only water or minerals. These results on the immediate effect of mineral amendments are in general agreement with the finding of no increase in N_2 fixation where there were field applications of P several months to several years before soils were sampled. In the field applications, no energy source was applied with the phosphorus, or if site preparation incorporated organic materials into the soil, the most readily available energy sources had been utilized by the time the sites were sampled.

Anaerobic spore-forming bacteria were the only microorganisms isolated that had a potential for N_2 fixation. These organisms were able to grow and fix N_2 under conditions unsuitable for aerobic bacteria or algae, and can survive adversity by forming spores.

The objectives of this study have been accomplished, but as is often the case a number of questions have arisen as a consequence of the findings. There is still no realistic assessment of the importance of anaerobic N_2 fixation in practical forestry. Burning has been shown to increase the fixation rate, but the mode of action of the burning effect is unknown. The practices of thinning and fertilization on short-term N_2 fixation have not been investigated. A concerted effort on these and other problems is required before the maximum economic and ecological benefits of natural N_2 fixation can be attained.

LITERATURE CITED

Allen, M. M., and R. Y. Stanier
1968. Selective isolation of blue-green algae from water and soil. J. Gen. Microbiol. 51: 203-209.

Brown, M. E., S. K. Burlingham, and R. M. Jackson
1962. Studies on Azotobacter species in soil. I. Comparison of media and techniques for counting Azotobacter in soil. Plant & Soil 17: 320-332.

Carlisle, A.
1965. Carbohydrates in the precipitation beneath a sessile oak Quercus petraea (Mattushka) Liebl. canopy. Plant & Soil 24: 399-400.

Daubenmire, R., and D. C. Prusso
1963. Studies of the decomposition rates of tree litter. Ecology 44: 589-592.

Davis, J. B., V. F. Coty, and J. P. Stanley
1964. Atmospheric nitrogen fixation by methane-oxidizing bacteria. J. Bacteriol. 88: 468-472.

Dilworth, M. J.
1966. Acetylene reduction by nitrogen-fixing preparations from Clostridium pasteurianum. Biochem. Biophys. Acta 127: 285-294.

Granhall, U. I. F., and E. Henriksson
1969. Nitrogen-fixing blue-green algae in Swedish soils. Oikos 20: 175-178.

Hardy, R. W. F., R. D. Holsten, E. K. Jackson, and R. C. Burns
1968. The acetylene-ethylene assay for N_2 fixation: Laboratory and field evaluation. Plant Physiol. 43: 1185-1207.

Jorgensen, J. R., and C. G. Wells
1971. Apparent nitrogen fixation in soil influenced by prescribed burning. Soil Sci. Soc. Am. Proc. 35: 806-810.

Jurgensen, M. F.
1967. The enumeration and identification of nonsymbiotic nitrogen-fixing microorganisms found in acid forest and nursery soils. Ph.D. Thesis. N. C. State Univ. Dep. Soil Sci., Raleigh, N.C., 158 p.

Koch, B., and H. J. Evans
1966. Reduction of acetylene to ethylene by soybean root nodules. Plant Physiol. 41: 1748-1750.

Lotti, T., R. A. Klawitter, and W. P. LeGrande
1960. Prescribed burning for understory control. USDA For. Serv. Southeast. For. Exp. Stn. Pap. 116. 19 p.

Rice, W. A., and E. A. Paul
1971. The acetylene reduction assay for measuring nitrogen fixation in waterlogged soil. Can. J. Microbiol. 17: 1049-1056.

Rice, W. A., and E. A. Paul
1972. The organisms and biological processes involved in asymbiotic nitrogen fixation in waterlogged soil amended with straw. Can. J. Microbiol. 18: 715-723.

Schöllhorn, R., and R. H. Burris
1966. Study of intermediates in nitrogen fixation. Fed. Proc. 24: 710.

Vlassak, K., E. A. Paul, and R. E. Harris
1973. Assessment of biological nitrogen fixation in grassland and associated sites. Plant & Soil 38: 637-649.

Jorgensen, J. R.

1975. Nitrogen fixation in forested Coastal Plain soils. USDA For. Serv. Res. Pap. SE-130, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

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USDA Forest Service Research Paper SE-131 June 1975

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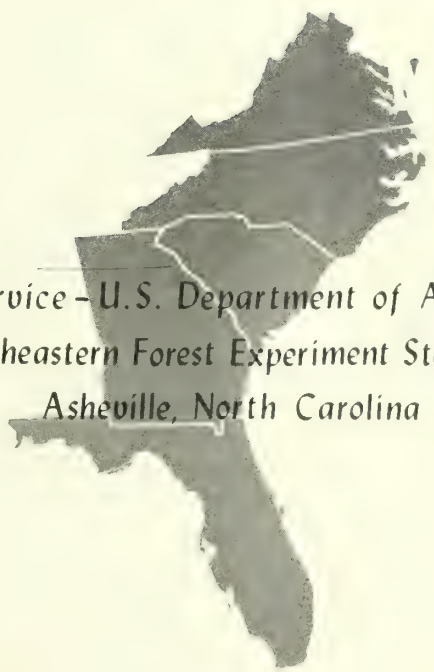

Forest Service - U.S. Department of Agriculture
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Mortality Factors Reducing the 1967-1969 Slash Pine Seed Crop in Baker County, Florida--A Life Table Approach

by

Gary L. DeBarr and Larry R. Barber

Slash pine, Pinus elliottii Engelm. var. elliottii, cone production in natural stands is cyclic, with large cone crops occurring about once every 3 years (Cooper 1957). Seed orchard managers strive to produce good seed crops every year; this is difficult to achieve since strobili development from flower primordia to seed maturation requires $2\frac{1}{2}$ growing seasons. During this timespan, strobili may be lost to numerous mortality factors.

This paper summarizes the known mortality factors that limit slash pine seed production, and presents partial life tables for the 1967-1969 seed crops in a north Florida slash pine seed production area. We call these "partial" life tables because observations are not complete for any single flowering cycle. Nevertheless, the preliminary data presented here illustrate how life tables can be constructed and used to evaluate cone and seed insect and disease impact in seed orchards.

WHY LIFE TABLES TO ANALYZE PINE SEED PRODUCTION?

Primordial flower buds of slash pine are initiated in July and August and the "female flowers" are recognizable in January of the following year. After pollination, the female strobili are classified as conelets until the third growing season (the year fertilization occurs and the cones mature seed) when the strobili are referred to as cones (Snyder 1972). Seed collected at harvest is only a part of the potential yield indicated by the number of female strobili initiated.

Little quantitative data are available on pre-harvest seed losses on slash pine. Merkel (1961) periodically examined slash pine strobili and found that the yield of sound seed was less than half the estimated potential yield. Most reports concern only one or two mortality factors, and losses have been based upon the proportion of the crop present at a particular point in the flowering cycle, usually at harvest.

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Life tables have several characteristics that make them ideal for analyzing pest management problems in seed orchards (Waters 1969; Harcourt 1970). First, life tables provide a method of determining the interval (month or stage of strobili development) in which the most significant mortality occurs. Second, the budgetary nature of the life table format permits a direct accounting of seed losses, and provides a sound basis for establishing economic loss thresholds. Third, life tables tabulate interacting biological events, instead of the isolated effects of only one or two destructive agents. In the seed orchard, where strobili are subject to an almost continuous barrage of hazards, the multifactor approach of the life table provides a method of studying mutual competition for the same host.

MORTALITY FACTORS LIMITING SLASH PINE SEED PRODUCTION

With the exception of a single disease, the important known mortality factors limiting slash pine seed production are insects. Losses caused by insect attacks may be negligible in good crop years and severe in years of almost complete cone crop failure. The principal insect genera known to cause strobili mortality or seed loss of slash pine are: Dioryctria (Lepidoptera: Phycitidae), Laspeyresia (Lepidoptera: Olethreutidae), Gnophothrips (Thysanoptera: Pholeothripidae), Tetyra (Hemiptera: Pentatomidae), Leptoglossus (Hemiptera: Coreidae), and one group of midges (Diptera: Cecidomyiidae). The reported effects of these agents on slash pine seed production are reviewed briefly below:

Dioryctria amatella (Hulst), D. abietella (D. & S.), and D. clarioralis (Wlk.).--In north Florida, these Dioryctria species are multivoltine. Moth flight periods, as noted by ultraviolet light-trap catches, occur principally during May, July, and October, with some activity in April, June, August, and September (Merkel and Fatzinger 1971). The biologies of the Dioryctria spp. were studied by Ebel (1963, 1965), Yearian and Warren (1964), Franklin and Coulson (1968), and others.

Dioryctria spp. larvae commonly infest conelets, cones, shoots, buds, and fusiform rust cankers, Cronartium fusiforme (Arthur) Hedgcock and Hahn, of slash pine. Attacks by Dioryctria spp. are readily identified by the copious amounts of resin or frass that exude from the larval gallery. Infested conelets nearly always die, as do conelets borne on infested shoots. While not all infested cones die, the yield is reduced to an average of only five seed per cone (Sartor and Neel 1971). Occasionally, an attack on a cone is "pitched-out" when resin flow is sufficient either to repel or kill the attacking larvae.

Laspeyresia anaranjada Miller and L. ingens Heinrich.--The slash pine seedworm, L. anaranjada, commonly infests slash pine cones; the occurrence of L. ingens is rare (Merkel 1963, 1967a). Laspeyresia moths oviposit on slash cones in late April and early May.

The larvae feed from seed to seed until the cones mature, then overwinter in a gallery constructed in the cone axis. From one to five larvae are found in a cone. Each larva consumes five to seven seeds, but the cone and undamaged seed survive.

Levels of Laspeyresia and Dioryctria infestations may be approximately equal, but Laspeyresia destroy fewer seed. Merkel and Ebel (1961) noted that while 73 percent of the cones they examined were infested with seedworms, only 10 percent of the potential seed yield was destroyed. Merkel (1967a, 1967b) stated that 2 to 10 percent of the slash pine seed crop was lost annually to L. anaranjada.

Gnophothrips fuscus (Morgan) (=piniphilus Cwfd.).--Thrips feed on female flower buds and strobili. Attacks are identified by the resin droplets which exude from the succulent strobili. After pollination, attacks cease as the conelets begin to harden. However, severely damaged strobili continue to die over a period of several months following the initial attack.

Despite their minute size, thrips damage and kill many strobili (DeBarr 1969). Injured strobili develop into deformed cones with reduced seed yields (DeBarr and Williams 1971). Ebel (1961) noted that on some trees attacks were negligible, but on others as high as 20 percent of the strobili were killed. DeBarr (1969) observed losses of 45 percent on heavily infested trees in a slash pine orchard.

Cronartium strobilinum (Arthur) Hedgcock and Hahn.--Infection by southern cone rust disease occurs when female slash pine strobili are receptive to pollen in January or February; the symptoms of hypertrophic growth, followed by the formation of yellow aeciospores, are not observable until April or May. Losses in recent years have been light, but the potential destructiveness of the disease is illustrated by losses of 18 percent of the 1957 conelet crop in Georgia and north Florida. In some areas, losses approached 100 percent (Hepting 1958).

Leptoglossus corculus (Say) and Tetyra bipunctata (H. & S.).--These seedbugs feed on slash pine conelets and cones. Nymphs and adults of both species destroy seed (DeBarr 1967). Second-instar L. corculus nymphs abort loblolly pine, P. taeda L., and shortleaf pine, P. echinata Mill., conelets (DeBarr and Ebel 1974). Prolonged adult feeding can also kill cones. From 7 to 21 percent of the seed harvested from three slash pine orchards were worthless because of late-season seedbug damage (DeBarr et al. 1972).

Cecidomyiidae.--At least one cone midge species, Resseliella silvana (Felt), is a primary feeder on cone scales and seeds. The yellow- to orange-colored midge larvae of several other species may be secondary in or on injured or dead cone scales (Ebel 1963). Incidence is usually low.

METHODS

Field procedure.--All female strobili clusters were tagged on each of 12 slash pines located in a seed production area on the Olustee Experimental Forest, Baker County, Florida. The trees varied from 43 to 55 feet in height, and were selected as being open-grown with well-developed crowns. Aluminum bands placed around the trunk of each tree prevented cone destruction by squirrels.

A complete inventory was made during the first week of June 1967 when all the conelet and cone clusters on the trees were tagged. In 1968, all new female flower clusters were tagged early in January. During the last week of each month, from June 1967 through September 1968, except November and December 1967, monthly records were made on the number of surviving conelets and cones, as well as the number lost to mortality factors.

The symptoms used to identify mortality factors known to affect slash pine seed production are summarized in table 1. All cones were collected in September of each year. The seed were extracted from cones which had not been damaged by Dioryctria spp. and examined radiographically, as previously described by DeBarr (1970), to determine seedbug damage. The cones were bisected with a cone cutter to determine the number of Laspeyresia spp. galleries per cone axis (DeBarr and Proveaux 1969).

Life table construction.--The life tables presented in this paper are the cohort type applicable to strictly even-aged populations (Waters 1969 and Harcourt 1970). The mortality-survival record was obtained from monthly observation of the same individual strobili in the same population. As strobili were lost, no new replacement strobili were added and the population terminated at harvest. In addition, the percentage values were calculated from the number of reproductive structures alive at the start, and thus are in absolute, rather than relative, terms.

Tables were constructed to show the stage or interval of strobili growth, the average number alive (1_x) at the beginning of each period, and the average number dying (d_x) within the stage or interval. In addition, the mortality factors (d_xF) are shown, along with a percentage mortality column ($100r_x$) based on the initial population.

Where sufficient data were available, analyses were run to determine if significant correlations existed between total number of conelets or cones present on a tree and the number or percentage loss for each mortality category. The coefficient of determination ($\bar{r}^2$) was also calculated to show the proportion of the total variability of the dependent variable (loss) that was associated with the independent variable (strobili present).

Table 1.--Mortality factors limiting slash pine seed production in north Florida

Stage of strobili development	Mortality factor	Symptoms	References
Conelet	Flash pine flower thrips, *Gnophothrips fuscus* (=*G. piniphilus* Cwfd.)	Female flower buds and succulent flowers with tiny, barely visible punctures and abrasions marked by beads of resin. Flower shrivels and dies; strobili that survive attacks gnarled and yield few seed.	Ebel 1961; DeBarr 1969; DeBarr and Williams 1971
	Southern cone rust, *Cronartium strobilinum*	Conelet several times normal size; ruptured scales reveal yellow aeciospores.	Hepting 1958
	Coneworms, *Dioryctria clarioralis*	Conelet tunneled; pitch blister formed by resin-covered webbing over entrance hole.	Ebel 1963, 1965
	Dioryctria spp. (shoot attacks)	Larval gallery in conelet-bearing shoot; conelets die.	Ebel 1965; Coyne and Allen 1956
	Abortion	Conelets without signs of injury, but cease development, die, and later drop off the shoots; Cause: may be physiological or due to feeding by seedbugs, *Tetyra* and *Leptoglossus*, or other insects.	DeBarr and Ebel 1974
	Missing	Conelets not found in later tallies (includes mechanical breakage).	
Cone	Coneworms, *Dioryctria* spp. (primarily *D. amatella*)	Resin, boring-frass mixture around entrance hole; definite gallery in and around cone axis; chewings and frass distinctly loose, when present; also with pitch blister *D. clarioralis*.	Ebel 1963, 1965
	Cone midges, Cecidomyiidae	Brown shrunken areas on cone surface, often with small orange-colored midge larvae hidden beneath damaged cone scales.	Ebel 1963
	Abortion	Cones without signs of injury, but cease development, die, and later drop off the shoots; Cause: may be physiological or due to feeding by seedbugs, *Tetyra* and *Leptoglossus*, or other insects.	DeBarr and Ebel 1974
	Missing	Cones not found in later tallies (includes mechanical breakage).	

continued

Table 1.--Mortality factors limiting slash pine seed production in north Florida (continued)

Stage of strobili development	Mortality factor	Symptoms	References
Seed	Seedworms, *Laspeyresia* spp. (primarily *L. anaranjada* but also some *L. ingens*)	Larval galleries present in cone axis; seeds packed with granular frass, often laid down in concentric rings visible on radiographs.	Merkel 1963, 1967; DeBarr 1970
	Seedbugs, *Leptoglossus corculus* and *Tetyra bipunctata*	On radiographs endosperm sunken, partially collapsed, or almost entirely missing.	DeBarr 1970
	Empty	Seed which show up on radiographs with no internal contents; Cause: may be fertilization failure, environmental or physiological factors, or feeding by *L. corculus* or *T. bipunctata*.	DeBarr 1970

RESULTS AND DISCUSSION

The life tables--1967 cone crop.--In 1967, more cones were lost to Dioryctria spp. attacks in the $3\frac{1}{2}$-month period from June to harvest than to any other mortality factor (table 2). Dioryctria spp. killed 29.7 percent of the cones and the average number of live cones per tree dropped from 160 to 105. Most of the attacks occurred prior to the June survey.

Table 2.--Partial life table for 1967 cone crop, Baker County, Florida

Reproductive structure	Month (x)	Mean number living cones per tree (1_x)[1]	Mortality factor (d_xF)	Mean number dying per tree (d_x)	Percent mortality ($100r_x$)
Cones	June[2]	160.7	Dioryctria	35.8	22.3
			Abortion	5.1	3.2
			TOTAL	40.9	25.5
	July	119.8	Dioryctria	7.8	4.9
			Abortion	.3	.2
			Missing	1.9	1.2
			TOTAL	10.0	6.3
	August	109.8	Dioryctria	.3	.2
			Abortion	.2	.1
			Missing	.8	.5
			TOTAL	1.3	.8
	September	108.5	Dioryctria	3.7	2.3
			Abortion	.1	.05
			Midges	.1	.05
			TOTAL	3.9	2.4
	Harvest	104.6		56.1	35.0

[1]Based upon complete tallies of 12 trees.
[2]Includes June mortality plus all previous spring mortality still recognizable.

1968 cone crop.--Shoot attacks by Dioryctria spp. in June and July 1967 were important in limiting the 1968 cone crop (table 3). Dioryctria spp. larvae boring in shoots killed 10 percent of the conelets, while direct attacks on conelets accounted for a loss of only 1 percent. This suggests that in certain years shoot attacks may severely affect the production of slash pine cone crops. Coyne and Allen (1956) reported a case in which only 32 percent of the longleaf pine, Pinus palustris L., conelet crop survived, primarily because D. amatella mined the conelet-bearing shoots.

Table 3.--Partial life table for 1968 cone crop, Baker County, Florida

Reproductive structure	Month (x)	Mean number living cones per tree (1x)[1]	Mortality factor (dxF)	Mean number dying per tree (dx)	Percent mortality (100rx)
Conelets	June (1967)[2]	318.3	Dioryctria	1.3	0.4
			Dioryctria (shoot)	27.0	8.5
			Abortion	4.6	1.4
			Thrips	1.1	.3
			Rust	.6	.2
			TOTAL	34.6	10.8
	July	283.7	Dioryctria	1.4	.4
			Dioryctria (shoot)	4.3	1.4
			Abortion	3.3	1.0
			Missing	7.3	2.3
			TOTAL	16.3	5.1
	August	267.4	Abortion	.9	.3
			Missing	5.4	1.7
			TOTAL	6.3	2.0
	September	261.1	Dioryctria	.9	.3
			Dioryctria (shoot)	.1	.1
			Abortion	.5	.1
			Missing	2.3	.7
			TOTAL	3.8	1.2
	October	257.3	Abortion	.2	.1
			Missing	5.1	1.6
			TOTAL	5.3	1.7
	November and December	252.0	Missing	16.2	5.1
			TOTAL	16.2	5.1
Cones	January (1968)	235.8	Dioryctria	.1	.05
			Abortion	.2	.05
			TOTAL	.3	.1
	February	235.5	Abortion	.3	.1
			Missing	1.1	.3
			TOTAL	1.4	.4
	March	234.1	Abortion	1.0	.3
			Missing	2.4	.7
			TOTAL	3.4	1.0
	April	230.7	Dioryctria	.5	.2
			Abortion	3.5	1.1
			Missing	.7	.2
			TOTAL	4.7	1.5
	May	226.0	Dioryctria	4.8	1.5
			Abortion	8.2	2.6
			Missing	3.6	1.1
			TOTAL	16.6	5.2

continued

[1] Based upon complete tallies of 12 trees.
[2] Includes June mortality plus all previous spring mortality still recognizable.

Table 3.--Partial life table for 1968 cone crop, Baker County, Florida (continued)

Reproductive structure	Month (x)	Mean number living cones per tree (1x)[1]	Mortality factor (dxF)	Mean number dying per tree (dx)	Percent mortality (100rx)
Cones	June[2]	209.4	Dioryctria	6.8	2.1
			Abortion	1.8	.5
			Midges	.1	.1
			Missing	.7	.2
			TOTAL	9.4	2.9
	July	200.0	Dioryctria	5.8	1.8
			Abortion	.5	.2
			Midges	.1	.1
			Missing	.3	.1
			TOTAL	6.7	2.2
	August	193.3	Dioryctria	5.9	1.9
			Abortion	.2	.1
			Missing	6.4	2.0
			TOTAL	12.5	4.0
	September	180.8		137.5	43.2

[1] Based upon complete tallies of 12 trees.
[2] Includes June mortality plus all previous spring mortality still recognizable.

Dioryctria spp. infestation of cones was less than 8 percent in 1968, compared to almost 30 percent the previous year. Part of this decrease in percentage infestation was due to a larger cone crop in 1968. But fewer cones per tree (23.9 vs. 47.6) were infested in 1968, perhaps because Dioryctria spp. moth populations were relatively low in 1968 (Merkel and Fatzinger 1971). The impact of thrips on the 1968 cone crop is not shown in table 3 because at the time of the June observations, only a few thrips-killed conelets remained on the trees.

1969 cone crop.--Thrips killed 16 percent of the 1969 cone crop. The attacks occurred in January and early February, but severely damaged conelets continued to die in March and April (table 4). Since conelet losses from thrips attacks are seldom detected in seed orchards, a life table analysis of seed production can put these losses in proper perspective. Once recognized as a major limiting factor, thrips damage can be prevented with insecticides (DeBarr and Matthews 1971).

Each year from 3 to 5 percent of the conelet or cone crop aborted. Aborted conelets and cones lacked apparent insect or mechanical damage. This mortality may have been due to unfavorable physiological or environmental conditions, but recent work on loblolly pine has shown that L. corculus feeding can induce conelet and cone abortion (DeBarr and Ebel 1974). Conelets and cones not found on subsequent examinations were categorized as missing. Most of these losses probably resulted from mechanical breakage, abortion, or insect attacks. Southern cone rust infected less than 1 percent of the conelet crop each year.

Table 4.--Partial life table for 1969 cone crop, Baker County, Florida

Reproductive structure	Month (x)	Mean number living cones per tree (1x)[1]	Mortality factor (dxF)	Mean number dying per tree (dx)	Percent mortality (100rx)
Conelets	January (1968)	426.6	Dioryctria (shoot)	0.5	0.1
			Abortion	.2	.1
			Thrips	1.2	.3
			TOTAL	1.9	.5
	February	424.7	Abortion	.8	.2
			Thrips	23.8	5.6
			Missing	3.4	.8
			TOTAL	28.0	6.6
	March	396.7	Dioryctria (shoot)	.3	.05
			Abortion	1.1	.2
			Thrips	38.7	9.1
			Rust	.1	.05
			Missing	6.3	1.5
			TOTAL	46.5	10.9
	April	350.2	Dioryctria (shoot)	1.8	.4
			Abortion	.2	.1
			Thrips	5.3	1.2
			Rust	.6	.1
			Missing	5.4	1.3
			TOTAL	13.3	3.1
	May	336.9	Dioryctria	.5	.1
			Dioryctria (shoot)	1.9	.4
			Abortion	2.5	.6
			Missing	5.1	1.2
			TOTAL	10.0	2.3
	June	326.9	Dioryctria (shoot)	1.5	.4
			Abortion	1.8	.4
			Missing	4.5	1.1
			TOTAL	7.8	1.9
	July	319.1	Dioryctria	.5	.1
			Abortion	4.8	1.1
			Missing	3.7	.9
			TOTAL	9.0	2.1
	August	310.1	Dioryctria	.3	.1
			Abortion	2.0	.4
			TOTAL	2.3	.5
	September	307.8		118.8	27.9

[1]Based upon complete tallies of 12 trees.

Influence of cone crop on insect infestation.--Lyons (1956, 1957) found that the intensity of insect damage was inversely related to conelet and cone production on red pine, P. resinosa Ait. Merkel et al. (1965) and Merkel (1967a) noted that the number of slash pine cones infested by Dioryctria spp. or Laspeyresia spp. was positively correlated with the number of cones per tree; the infestation percentage was negatively

correlated with cone crop size. Positive correlations for insect damage and the number of cones per shortleaf pine, P. echinata Mill., tree were also reported by Coulson and Franklin (1970). Abrahamson and Kraft (1965) found that the population density of a seedworm, Laspeyresia toreuta (Grote), was positively correlated with the cone crop size of jack pine, P. banksiana Lamb.

Yearian and Warren (1964) observed that loblolly pine trees bearing good cone crops generally had higher percentages of cones damaged by insects than trees with poor cone crops. Hedlin (1964) hypothesized that limited cone crops of Douglas-fir, Pseudotsuga menziesii (Mirb.) Franco var. menziesii, are severely damaged while good cone crops are lightly damaged. Mattson (1971) found that in natural red pine stands thinned for seed production areas, the size of the cone crop fluctuated almost unpredictably from year to year, but the number of insect-attacked cones tended to increase unless limited by cone numbers. He concluded that cone crop size is highly important in regulating cone-insect populations, and damage will be greatest in areas where the crop varies little from year to year.

We found positive correlations between the number of strobili affected by insects and the total number of strobili present the first tally of each year (table 5). Mostly negative correlations existed between the infestation percentage and the crop size per tree. The intensity of Laspeyresia spp. infestation (i.e., number of larvae per cone) was also negatively correlated with number of cones available for attack. Our data suggest that while the absolute number of insect attacks usually increases significantly as the size of the slash pine cone crop increases, the percent mortality or infestation may actually decrease slightly and bear no significant relation to cone crop size.

Table 5.--Correlations between insect infestation and cone crop size

Mortality factor	Year	Variable			
		Number of cones infested		Percent infestation	Number of larvae per cone
		r	r^2	r	r
Dioryctria spp. (shoot attacks)	1967	0.70*	0.49	-0.005	--
	1968	0.76**	0.58	+0.29	--
Dioryctria spp. (cone attacks)	1967	0.62*	0.39	-0.36	--
	1968	0.15	--	-0.21	--
Laspeyresia spp. (cone attacks)	1967	0.83**	0.69	-0.29	-0.27
	1968	0.69*	0.48	-0.37	-0.33
Thrips (flower kill)	1968	0.84**	0.71	-0.002	--

*Significant at the 0.05 level of probability.
**Significant at the 0.01 level of probability.

This may be a delayed density-dependent relationship; i.e., the population of the parasite lags behind that of its host when the host population is increasing. If this is true, a sudden increase in cone initiation at approximately 3-year intervals might insure that relatively insect-free slash pine cone crops would occur periodically. This hypothesis is supported by the majority of data found in the literature. It does not necessarily disagree with the work of Yearian and Warren (1964), since their data may have been taken during a period of decreasing cone production.

Based upon our data and a survey of the literature, it seems likely that in seed orchards managed to insure a relatively stable annual crop, cone and seed insects may have an even greater impact on seed yield than they now have in natural stands.

The life table approach in seed orchard operations.--The partial life tables we present for the 1967-1969 seed crops in our north Florida study area can be used as a guide to the various mortality factors limiting slash pine seed production in other areas. Obviously, their relative importance will vary from orchard to orchard, as well as from year to year. Surveys of broader scope and duration would be useful in order to develop complete life tables for slash pine seed crops which could be compared in both time and location; i.e., among orchards, as well as among years. Table 6 summarizes our life table data by seed yield (number of seed per tree and pounds of seed per tree). By using the value per pound that the orchard manager places on his seed, he could compute the monetary value of seed lost to each mortality factor. Thus, a crop life table approach would allow the appraisal of each mortality factor by the dollar value of the seed loss.

Table 6. --Impact of insects and other factors on seed yields of slash pine in North Florida, 1967-1969

Reproductive structures	Cone crop	Mean potential yield (seed per tree)[1]	Mortality factor	Loss of seed		
				Seed per tree	Percent loss	Pounds per tree[2]
Cones (June 1967 - September 1967)	1967	16,070	Dioryctria spp.	4,760	29.6	0.397
			Abortion	560	3.5	.047
			Midges	15	.1	.001
			Missing	270	1.7	.023
			TOTAL	5,605	34.9	.468
Seed		10,460	Laspeyresia spp.[3]	305	1.9	.025
			Seedbugs[4]	545	3.4	.045
			Empty	660	4.1	.055
			TOTAL	1,510	9.4	.125
Harvest = 8,950						
Conelets (June 1967 - December 1967)	1968	31,830	Dioryctria spp.	350	1.1	.029
			Dioryctria (shoot)	3,150	9.9	.263
			Abortion	955	3.0	.080
			Thrips	95	.3	.008
			Cone rust	65	.2	.005
			Missing	3,630	11.4	.303
			TOTAL	8,245	25.9	.688
Cones (January 1968 - September 1969)		23,585	Dioryctria spp.	2,390	7.5	.199
			Abortion	1,590	5.0	.133
			Missing	1,530	4.8	.128
			TOTAL	5,510	17.3	.460
Seed		18,080	Laspeyresia spp.[3]	335	1.0	.028
			Seedbugs[4]	1,665	5.2	.139
			Empty	1,680	5.3	.140
			TOTAL	3,680	11.5	.307
Harvest = 14,400						
Conelets (January 1968 - September 1968)	1969	42,660	Dioryctria	130	.3	.011
			Dioryctria (shoot)	600	1.4	.050
			Abortion	1,320	3.1	.110
			Thrips	6,910	16.2	.576
			Cone rust	85	.2	.007
			Missing	2,860	6.7	.238
			TOTAL	11,905	27.9	.992

[1] Based upon observations on 12 trees and assuming a potential of 100 seed per cone.
[2] Assuming 12,000 seed per pound.
[3] Assuming each Laspeyresia spp. larvae destroys six seed per cone (Merkel 1967).
[4] Detectable damaged seed only.

LITERATURE CITED

Abrahamson, L. P., and K. J. Kraft
1965. A population study of the cone moth Laspeyresia toreuta Grote in Pinus banksiana stands. Ecology 46: 561-563.

Cooper, R. W.
1957. Silvical characteristics of slash pine (Pinus elliottii, Engelm. var. elliottii). USDA For. Serv. Southeast. For. Exp. Stn. Pap. 81, 13 p. Asheville, N. C.

Coulson, R. N., and R. T. Franklin
1970. Populations of Dioryctria spp. (Lepidoptera: Phyticidae) in relation to cone destruction. J. Ga. Entomol. Soc. 5: 197-202.

Coyne, J., and R. M. Allen
1956. Spraying of genetically selected pine trees to reduce seed loss caused by insects. Assoc. South. Agric. Work. Proc. 1956: 139-140.

DeBarr, G. L.
1967. Two new sucking insect pests of seed in southern pine seed orchards. U.S. For. Serv. Res. Note SE-78, 3 p. Southeast. For. Exp. Stn., Asheville, N. C.

DeBarr, G. L.
1969. The damage potential of a flower thrips in slash pine seed orchards. J. For. 67: 326-327.

DeBarr, G. L.
1970. Characteristics and radiographic detection of seed bug damage to slash pine seed. Fla. Entomol. 53: 109-117.

DeBarr, G. L., and B. H. Ebel
1974. Conelet abortion and seed damage of shortleaf and loblolly pines by a seed-bug, Leptoglossus corculus. For. Sci. 20: 165-170.

DeBarr, G. L., and F. R. Matthews
1971. Mist-blower applications for control of flower thrips and southern cone rust in a slash pine seed orchard. J. Econ. Entomol. 64: 520-522.

DeBarr, G. L., E. P. Merkel, C. H. O'Gywnn, and M. H. Zoerb, Jr.
1972. Differences in insect infestation in slash pine seed orchards due to phorate treatment and clonal variation. For. Sci. 18: 56-64.

DeBarr, G. L., and M. T. Proveaux
1969. A new table model cone cutter. USDA For. Serv. Tree Plant. Notes 19(4): 19-20.

DeBarr, G. L., and J. A. Williams
1971. Nonlethal thrips damage to slash pine flowers reduces seed yields. USDA For. Serv. Res. Note SE-160, 4 p. Southeast. For. Exp. Stn., Asheville, N. C.

Ebel, B. H.
1961. Thrips injure slash pine female flowers. J. For. 59: 374-375.

Ebel, B. H.
1963. Insects affecting seed production of slash and longleaf pines--their identification and biological annotation. U.S. For. Serv. Res. Pap. SE-6, 24 p. Southeast. For. Exp. Stn., Asheville, N. C.

Ebel, B. H.
1965. The Dioryctria coneworms of north Florida pines (Lepidoptera: Phycitidae). Ann. Entomol. Soc. Am. 58: 623-630.

Franklin, R. T., and R. N. Coulson
1968. Insects affecting seed production of shortleaf pine in the Georgia Piedmont. Can. Entomol. 100: 807-812.

Harcourt, D. G.
1970. Crop life tables as a pest management tool. Can. Entomol. 102: 950-955.

Hedlin, A. F.
1964. Results of a six-year plot study on Douglas-fir cone insect population fluctuations. For. Sci. 10: 124-128.

Hepting, G. H.
1958. Southern cone rust. USDA For. Serv. For. Pest Leafl. 27, 4 p.

Lyons, L. A.
1956. Insects affecting seed production in red pine. I. Conophthorus resinosae Hopk. (Coleoptera: Scolytidae). Can. Entomol. 88: 599-608.

Lyons, L. A.
1957. Insects affecting seed production in red pine. IV. Recognition and extent of damage to cones. Can. Entomol. 89: 264-271.

Mattson, W. J., Jr.
1971. Relationship between cone crop size and cone damage by insects in red pine seed-production areas. Can. Entomol. 103: 617-621.

Merkel, E. P.
1961. A study of losses in the 1960 slash pine cone crop. USDA For. Serv. Res. Note 164, 2 p. Southeast. For. Exp. Stn., Asheville, N.C.

Merkel, E. P.
1963. Distribution of the pine seedworm, Laspeyresia anaranjada, with notes on the occurrence of Laspeyresia ingens. Ann. Entomol. Soc. Am. 56: 667-669.

Merkel, E. P.
1967a. Individual slash pines differ in susceptibility to seedworm infestation. J. For. 65: 32-33.

Merkel, E. P.
1967b. Life history of the slash pine seedworm, Laspeyresia anaranjada Miller (Lepidoptera: Olethreutidae). Fla. Entomol. 50: 141-149.

Merkel, E. P., and B. H. Ebel
1961. Cone and seed insects and their control. Sixth South. Conf. For. Tree Improv. Proc. 1961: 137-141.

Merkel, E. P., and C. W. Fatzinger
1971. Periodic abundance of pine cone-infesting Lepidoptera in black light traps and sleeve cages in north Florida. Fla. Entomol. 54: 53-61.

Merkel, E. P., A. E. Squillace, and G. W. Bengtson
1966. Evidence of inherent resistance to Dioryctria infestation in slash pine. Eighth South. Conf. For. Tree Improv. Proc. 1965: 96-99.

Sartor, C. F., and W. W. Neel
1971. Impact of Dioryctria amatella on seed yields of maturing slash and loblolly pine cones in Mississippi seed orchards. J. Econ. Entomol. 64: 28-30.

Snyder, E. B.
1972. Glossary for forest tree improvement workers. USDA For. Serv., 22 p. South. For. Exp. Stn., New Orleans, La.

Waters, W. E.
1969. The life table approach to analysis of insect impact. J. For. 67: 300-304.

Yearian, W. C., and L. O. Warren
1964. Insects of pine cones in Arkansas. J. Kansas Entomol. Soc. 37: 259-264.

DeBarr, Gary L., and Larry R. Barber
1975. Mortality factors reducing the 1967-1969 slash pine seed crop in Baker County, Florida--a life table approach. USDA For. Serv. Res. Pap. SE-131, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

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by

Vicki H. Fedde

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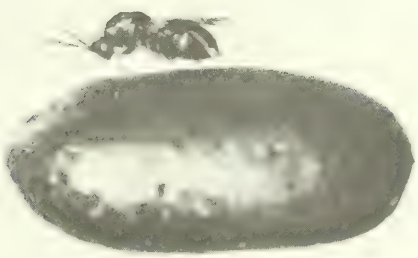

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Development and Emergence of *Monodontomerus dentipes* Dalman[1], A Parasite of Pine Sawflies[2]

by

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Monodontomerus dentipes (Dalman), a parasite of cocoons of pine sawflies, commonly attacks *Diprion pini* L., *D. polytomum* (Hartig), and *D. similis* (Hartig) in Europe. When the introduced pine sawfly, *D. similis*, was accidentally imported into the United States, *M. dentipes* accompanied it as one of a nine-species-parasite complex. Since then, *M. dentipes* has been a key factor in the control of *D. similis* and other diprionid sawflies in the United States and Canada. The parasite has been reported on 11 species of sawflies in the family Diprionidae and, although *Diprion* sp. are the most common, five *Neodiprion* sp. have been reported as hosts.

Several *Neodiprion* sp. attack pines in the Southeastern United States, causing various degrees of damage. *Neodiprion lecontei* (Fitch), *N. merkeli* Ross, *N. excitans* Rohwer, *N. abbotii* (Leach), and *N. compar* (Leach) in Florida are possible targets for control by *M. dentipes*, for example.

For a successful biological control program against these sawflies, the life histories of the hosts and parasite must be understood. Morris et al. (1937) and Mertins (1967) discussed some aspects of the biology of *M. dentipes*. Mertins and Coppel (1971) reviewed much of the information covered by Mertins (1967). These, along with other references to *M. dentipes*, were summarized by Fedde (1974). Little is known, however, about the early instars, feeding, emergence patterns, and behavior of the parasite. The following report supplements current information about the biology of *M. dentipes*.

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[1] Hymenoptera: Torymidae.

[2] This paper was part of a thesis submitted in partial fulfillment of the degree of Master of Science in Entomology, N.C. State University, Raleigh. The research was supported by the USDA Forest Service and personal funds.

Mention of trade names in this paper does not constitute endorsement by the U.S. Department of Agriculture.

MATERIALS AND METHODS FOR LABORATORY REARING

A colony of M. dentipes was maintained at the Forestry Sciences Laboratory, Research Triangle Park, N. C., from May 1969 to November 1970. Original adults were reared from cocoons of D. similis collected near Amery, Wisconsin. Subsequent generations of the parasite were reared on cocoons of N. lecontei (Fitch), N. excitans Rohwer, and N. merkeli Ross collected in Florida.[3] Usually 60 to 100 adults of M. dentipes were released into mating cages (18 by 18 by 13 cm) with 32-mesh Saran screen backs and sliding Plexiglas fronts, similar to those described by Nicholls (1963).

The adults were fed 10 percent aqueous honey on pieces of dental cotton and split raisins soaked in water overnight. Food was changed daily except weekends and cages were sprayed with atomized water to provide moisture droplets for the parasites. Unparasitized sawfly cocoons were exposed to the parasites for about 24 hours for oviposition. They were removed from the cages, placed in No. 0 gelatin capsules, and held in small plastic boxes in desiccator jars at 75 percent relative humidity and ambient room temperatures until adult parasites emerged. The cocoons were checked daily. Information about emergence, mating, and oviposition was obtained from the general rearing. Unless stated otherwise, these procedures were followed in all experiments, as well as in the general rearing.

FEEDING, LONGEVITY, AND OVIPOSITION OF ADULT

Feeding Behavior

In a preliminary examination of the feeding behavior of M. dentipes, 100 mated females were caged in groups of 5 in oviposition cages (10 by 10 by 6 cm) similar to those described by Nicholls (1963). Needle fascicles of Pinus taeda L. were clipped just distal to the sheath. The basal portion of the needles, prepupae of N. lecontei, split water-soaked raisins, and 10 percent aqueous honey were offered to the adults continuously from the time they emerged from the host cocoons. None of the parasites were observed feeding on pine needle fascicles or the sawfly prepupae in 20 hours of observation over a 3-day period; however, they fed frequently on the honey-water and raisins.

To determine whether mated females of M. dentipes fed more frequently on honey-water or raisins, 72 individuals were caged separately after a starvation and mating period of several hours following emergence from the host cocoons. Honey-water and split, water-soaked raisins were placed in the cages at 1:30 p.m. on the first day of observation. Food was removed at 4:30 p.m. and replaced the next morning at 8:15 a.m. Each observation period consisted of 15-minute intervals from 1:30 to 4:15 p.m. and from 8:30 a.m. to 1:15 p.m. on the following day. Thus, the observation day consisted of the afternoon plus the following morning. There were five observation days. Incidences of feeding were grouped into 45-minute classes for statistical analyses since very few parasites fed at any one 15-minute interval.

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[3] The cooperation of Drs. H. C. Coppel and J. W. Mertins, of the University of Wisconsin, and Dr. R. C. Wilkinson of the University of Florida, is gratefully acknowledged.

The mean number of feedings per day was 33.20 ± 16.13 SD (5). Of these, there were 17.60 ± 4.72 SD (5) feedings per day on honey-water and 15.60 ± 12.17 SD (5) feedings per day on raisins. The insects fed more frequently in the afternoon, when 62.8 percent of the feedings on raisins, 81.8 percent of the feedings on honey-water, and 72.9 percent of the total feedings occurred.

During periods of greater feeding incidence, i.e., in the afternoons, the total number of feedings for each class appeared almost directly proportional to the feedings on honey-water (fig. 1). The correlation coefficient for total number of feedings and the number on honey-water was 0.9724 ± 0.511 SE (5) for total feedings and 0.7976 ± 0.644 SE (5) for feedings on raisins. The slope of the line representing the relationship of total feedings to feedings on honey-water is 0.708; on raisins, 0.284. In situations where the number of feedings was very low, i.e., mornings, feedings on raisins accounted for most of the total feedings (fig. 2).

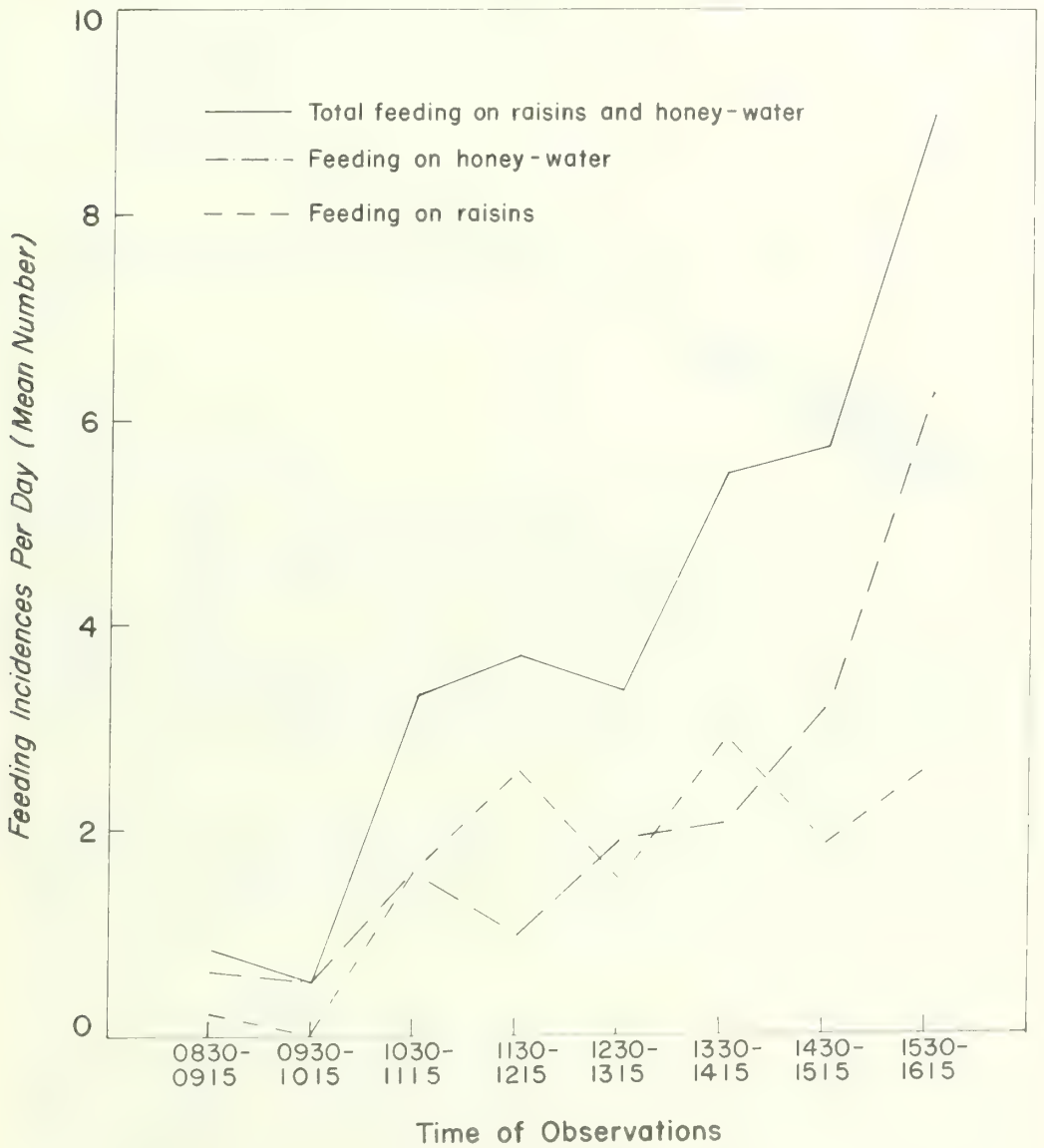

Figure 1.--Mean incidences of feeding on honey-water and split, water-soaked raisins over a 5-day period by 72 mated females of Monodontomerus dentipes (Dalman).

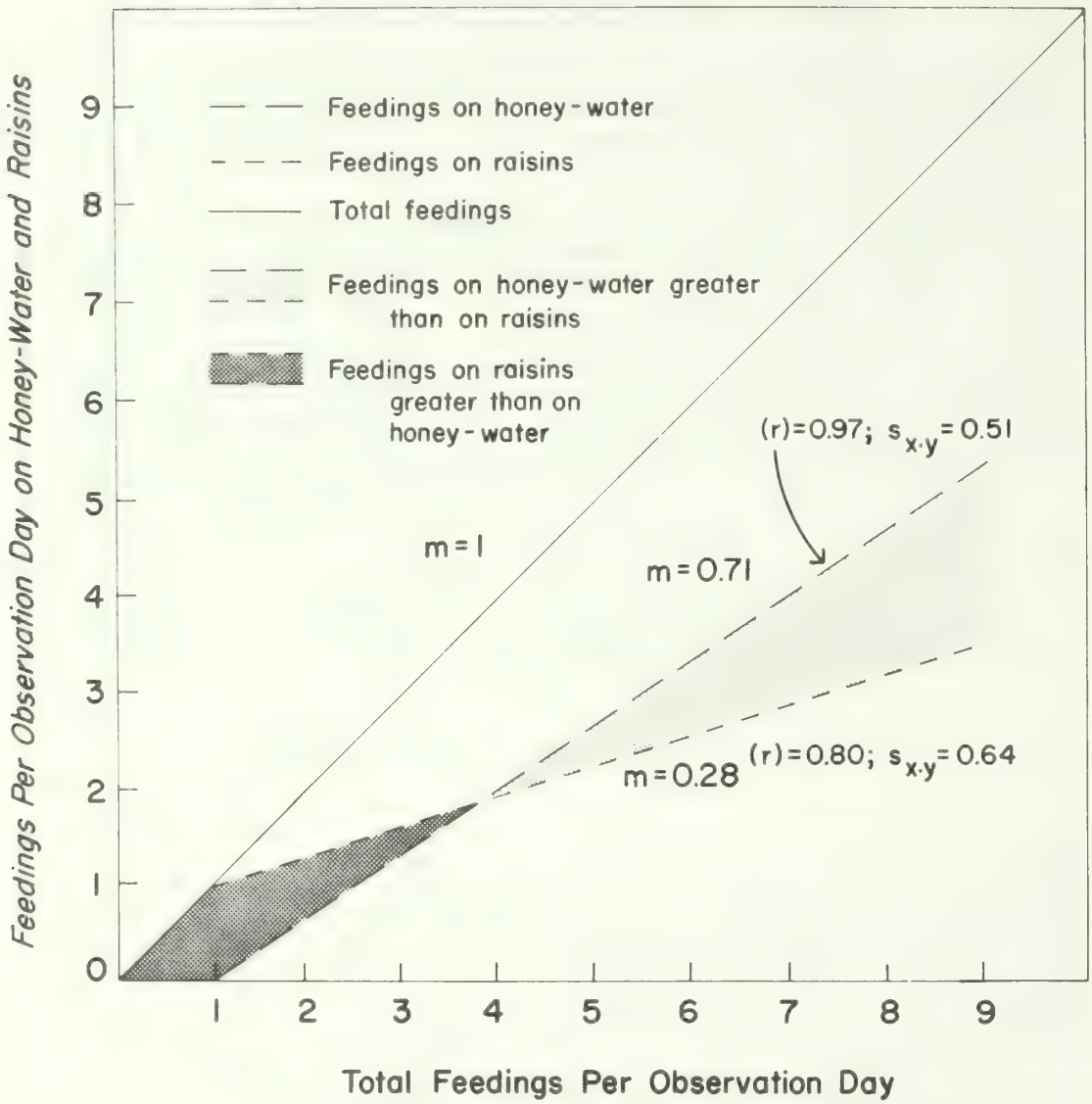

Figure 2.--The dependence of total feeding incidences in 72 mated females of Monodontomerus dentipes (Dalman) on the feeding incidences on honey-water and raisins. The approximation of the lines representing incidences of feeding on honey-water and raisins to the line with slope (m) = 1.0 indicates the extent to which that food influenced the total number of feedings.

The composition of total number of feedings also changed from day to day during the 5-day period. On the first day, feeding on raisins accounted for 62.7 percent of the total incidences of feeding; on the second day, 28.6 percent; on the third day, 43.6 percent; on the fourth day, 28.0 percent; and on the fifth day, 50 percent.

Longevity of Adult Females

The longevity of mated females of M. dentipes was determined from 36 individuals caged separately. They were fed honey-water and raisins, and the cages were sprayed with atomized water each day. In addition, one N. lecontei cocoon was provided daily for oviposition. The mean survival time (days) of the females was 29.11 $\pm$ 10.81 SD; the range of survival time was 1 to 40 days.

To determine how survival time and oviposition are affected by density of females in each cage, 1, 2, 4, 8, and 16 females were placed in each cage. This sequence was replicated five more times. The parasites were fed honey-water and raisins, sprayed with water, and given one cocoon of N. lecontei daily for oviposition. Differences in mean survival time of the individuals at the five densities were not significant (table 1). Although some of the females survived 40 days, survival declined rapidly after 15 days (fig. 3).

Table 1.--Longevity of mated females of Monodontomerus dentipes (Dalman) at densities of 1, 2, 4, 8, and 16 females per 650 cm^3 cage (six replications)

Females per cage (number)	Survival time (days)[1]	
	($\bar{x}$ ± S.D.)	Range
1	32.17 ± 9.06	17 - 40
2	23.00 ± 8.55	15 - 33
4	28.71 ± 11.08	15 - 40
8	31.10 ± 7.26	15 - 40
16	28.66 ± 8.77	12 - 40

[1] $F = 1.752$; df (among density groups) = 4; df (within density groups) = 181.

Oviposition Behavior

Three distinct processes composed the oviposition behavior of M. dentipes: (1) Search for and examination of the host cocoon; (2) repeated thrusts of the ovipositor into the cocoon without actual oviposition; and (3) deposition of eggs. Generally, the female walked around the floor of the cage, drumming the surface occasionally with her antennae. When the host cocoon was located by the female, she climbed onto it. Often she walked across the cocoon once or twice and abandoned it for another. Before ovipositing, she examined the host cocoon closely, pacing its length, breadth, and circumference repeatedly. During this examination, the female tapped her elbowed antennae, one at a time, against the walls of the cocoon. During the immobilization of the host or egg deposition, the antennae remained in a relatively fixed position, elbowed downward. The long, extended ovipositor was drawn up under the abdomen and with apparent difficulty it was pushed through the tough wall of the host cocoon by abdominal movements. The sheath of the ovipositor was withdrawn and the abdomen moved in a circular fashion so that the ovipositor located the host prepupa within the cocoon. The abdomen was then pumped up and down, pushing the ovipositor into and almost withdrawing it from the host cocoon (fig. 4). Then the ovipositor was withdrawn. Often the female backed up and brushed the tips of her antennae over the hole made by the ovipositor. After further examination, she repeated the puncture and associated behavior at a different spot on the same cocoon. The procedure might be repeated several times before the female left the host cocoon. Often several females were observed ovipositing on the same host cocoon.

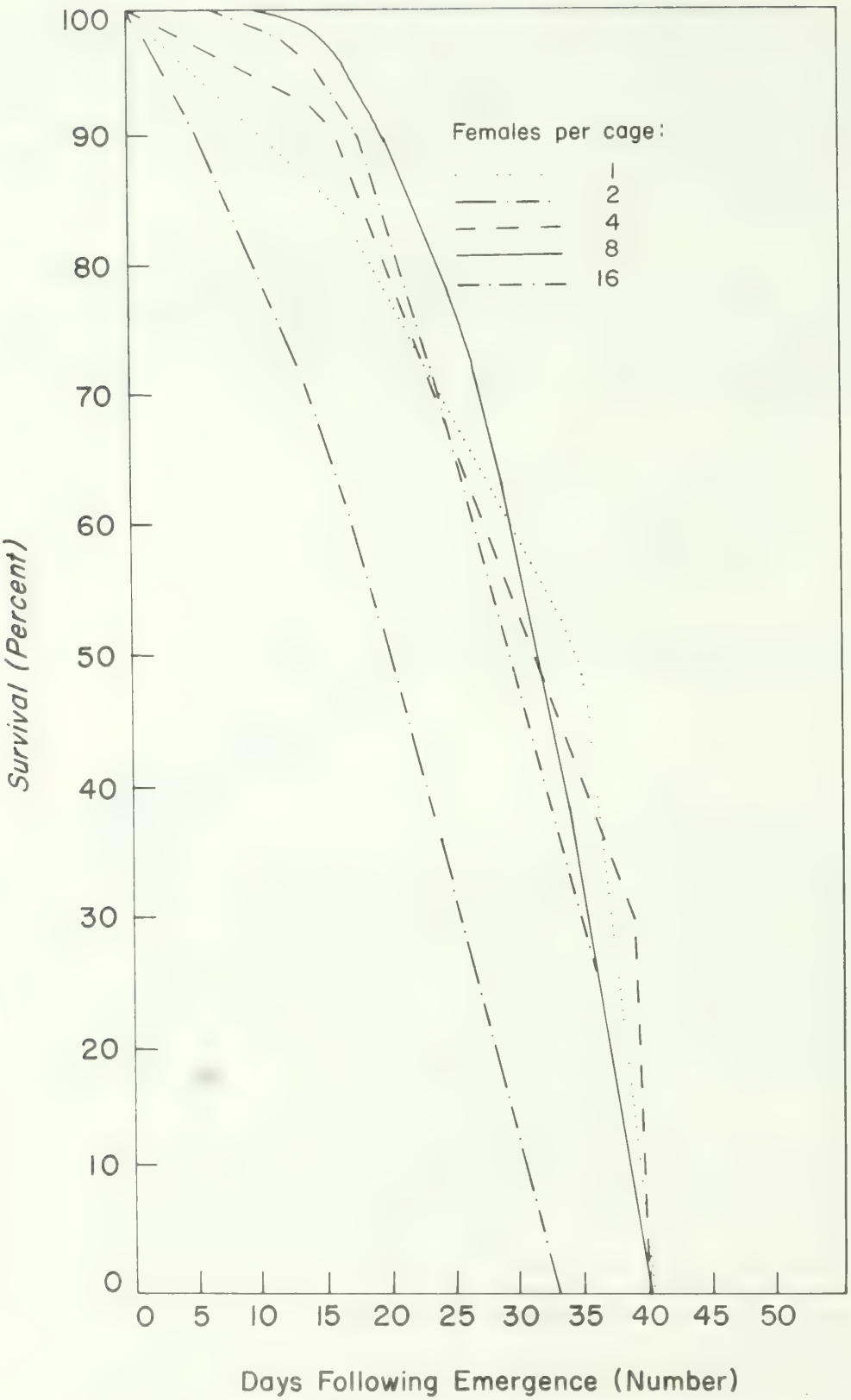

Figure 3.--Survivorship of adult females of Monodontomerus dentipes (Dalman) in the laboratory with 1, 2, 4, 8, and 16 individuals per 650 cm^3 cage.

Figure 4.--A female of Monodontomerus dentipes (Dalman) ovipositing in a cocoon of Neodiprion lecontei (Fitch). (Photo by A. T. Drooz.)

An attempt to quantify the oviposition of one female is given in table 2. There was no consistent change in the duration of searching in the five repetitions of oviposition behavior of the one female on a single cocoon. Neither were there apparent patterns in the number of unsuccessful attempts at oviposition, the duration of the host immobilization and egg deposition phases, or the number of thrusts of the ovipositor in the five repetitions of oviposition behavior. However, with more than one female, an observer might find that a trend exists in the mean number of thrusts of the ovipositor per minute from one repetition to another. Even though data were insufficient to allow definite conclusions, the number of thrusts of the ovipositor per minute appears to increase steadily from the first to the fifth repetition of oviposition behavior by one female on a single host cocoon.

Table 2.--Phases in the oviposition behavior of one female of Monodontomerus dentipes (Dalman) on one cocoon of the host Neodiprion lecontei (Fitch)

Behavior	Repetition on same host cocoon				
	1	2	3	4	5
Searching the host cocoon					
Duration (minutes)	2	5	3	2	3
Unsuccessful attempts at oviposition (number)	3	7	3	5	2
Immobilizing host and egg deposition					
Duration (minutes)	19	9	10	6	15
Thrusts of oviposition (number)	84	41	61	39	95
Thrusts per minute (mean number)	4.4	4.6	6.1	6.5	6.3

The Pattern of Oviposition

Host cocoons exposed to 40 newly emerged, mated, and separately caged females were dissected 3 days after exposure to the parasites to determine the number of eggs laid daily (fig. 5). Six of the females died within a few days or without ovipositing at all; analysis was based on oviposition by the 34 surviving females.

A minimum preoviposition period of 3 days was exhibited by four individuals; the maximum, 13 days, by three individuals. The mean preoviposition period (days) was 6.63 $\pm$ 2.61 SD (34). From 1 to 11 eggs were laid by females on their first day of oviposition. The 34 females of M. dentipes which oviposited survived 30.12 $\pm$ 9.06 SD days and laid 22.97 $\pm$ 12.64 SD eggs each. The number of eggs per female ranged from 5 to 54. No strong correlation was evident between the length of the preoviposition period and either the number of eggs laid on the first day of oviposition[4] or the total number of eggs produced.[5]

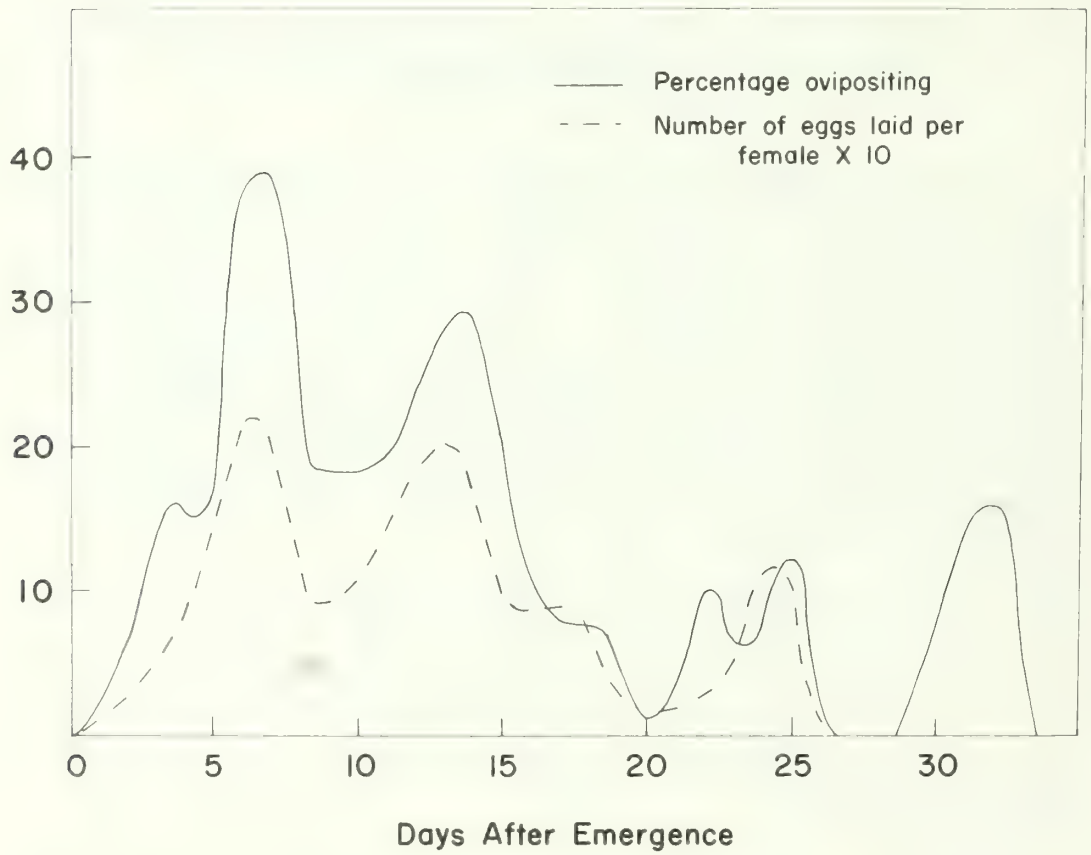

Figure 5.--Weighted moving average of the number of eggs produced per female of Monodontomerus dentipes (Dalman) and the percentage of females ovipositing.

[4] Correlation coefficient (r) = 0.294; $S_{x \cdot y}$ = 2.87.
[5] Correlation coefficient (r) = 0.132; $S_{x \cdot y}$ = 5.05.

The distribution of the percentage of the 34 females ovipositing and the distribution of the number of eggs produced per female over the 35-day period were similar (fig. 5). Both values increased sharply after 4 to 5 days and reached their maximum on the sixth day after emergence from the host cocoon. Thereafter, both egg production per female and the percentage of females ovipositing declined. Both values rose to a second peak on the thirteenth day. After about the seventeenth day, egg production and the number of females ovipositing fell almost to zero. A few females produced eggs on the thirty-third day following emergence, but the mean number of eggs produced per female was negligible past the twenty-fifth day.

DEVELOPMENT IN THE HOST COCOON

Egg Development

The egg of M. dentipes was slightly crescent shaped and cylindrical (fig. 6). Its mean length (mm) was 0.614 ± 0.024 SD (17) and its width, 0.182 ± 0.007 SD (17). One end of the egg tapered gradually, but widened again near the tip to form a small translucent knob. This end was adhesive and lacked the funnel-shaped spicules which covered the remainder of the egg. The opposite end tapered less gradually and was bluntly rounded at the tip.

The egg adhered to the body wall of the host, either by the adhesive knob, or by the spicules along the convex side of the egg which are evenly distributed over the remainder of the egg. They were present when the egg was oviposited and remained on the egg shell after hatch. Their arrangement on the egg surface was not uniform, although they fell generally into longitudinal rows.

To determine time to hatch, 165 eggs of M. dentipes were removed from the host, placed in separate gelatin capsules, and observed daily. Within 24 hours of oviposition, a distinct embryo could be seen within the chorion with the aid of a compound microscope (fig. 6). Within 48 hours, the embryo became visibly differentiated into head and body and the gut could be seen. Eclosion occurred on the second day for 38.18 percent of the eggs, on the third day for 43.64 percent, on the fourth day for 3.64 percent, and on the sixth day for 0.61 percent (fig. 6). The remaining 13.94 percent of the eggs failed to hatch. The mean duration (days) of the egg stage was 2.62 ± 0.64 SD (142).

Ten cocoons of N. lecontei, exposed overnight to mated adults of M. dentipes, were dissected under a stereoscopic microscope to determine whether or not eggs of M. dentipes were concentrated on any particular region of the host body or the host cocoon. Wilkinson[6] observed that sawfly prepupae, when confined to a small gelatin capsule and then probed, defended themselves by changing position. For the sake of reference, the terminology used to describe location of eggs on the prepupa or cocoon depends on the position of the host at the time of dissection. Nine of the dissected cocoons had been parasitized. Of the 82 eggs of M. dentipes which were found, 41 were on the prepupae of the hosts and 41 were on the inside walls of the host cocoons (table 3). Approximately 18 percent of the eggs were found in the anterior ends of the host cocoons and on the heads of the host prepupae; 37.18 percent in the middle portion of the cocoons and on the thorax of the host prepupae; and 43.9 percent in the posterior end of the cocoons and on the abdomen of the host prepupae. Eggs were not noticeably clustered nor were they concentrated in any particular area.

[6] Wilkinson, R. C. 1973. Personal communication. Univ. Fla. at Gainesville.

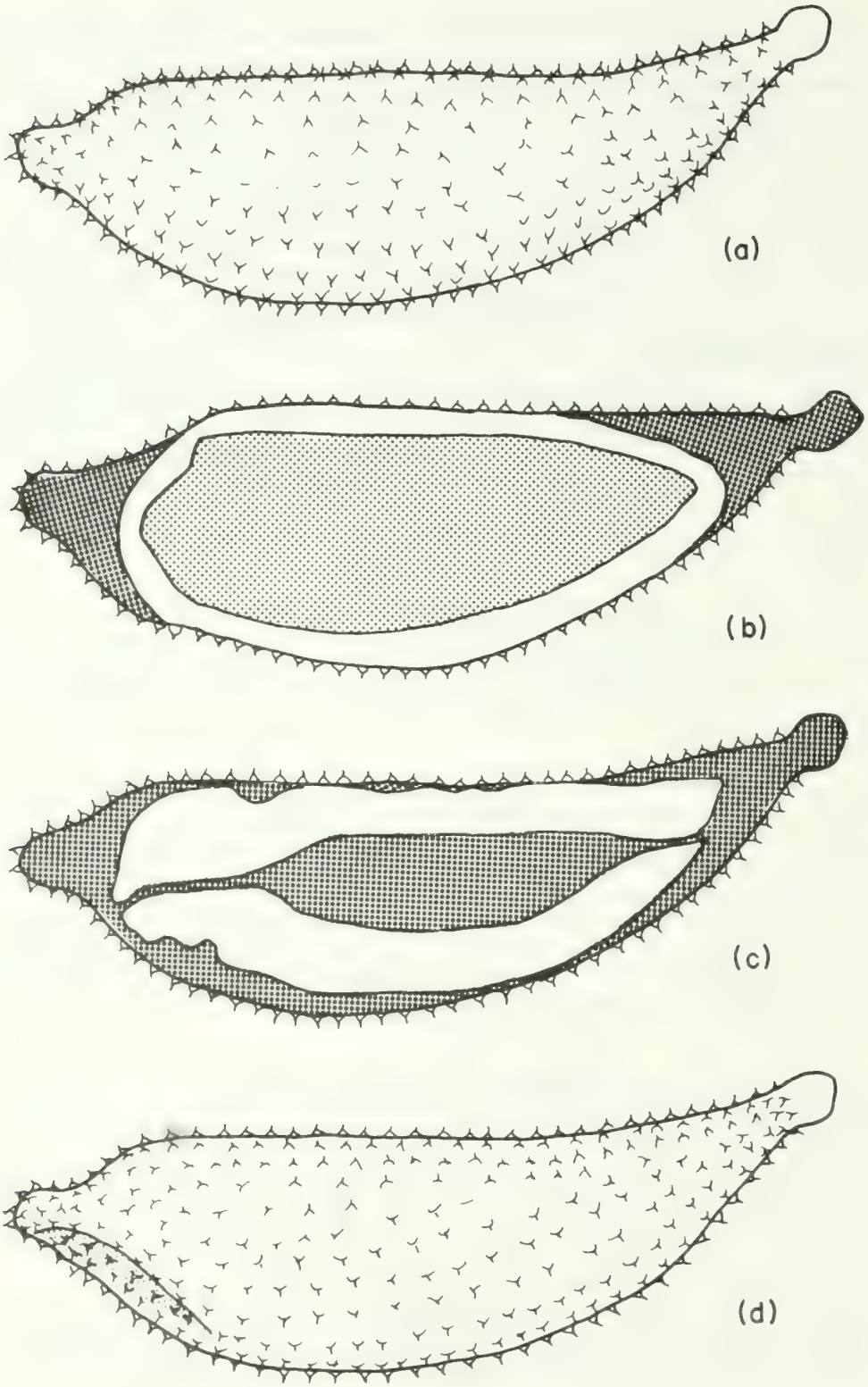

Figure 6.--Eggs of Monodontomerus dentipes (Dalman): (a) whole egg immediately after oviposition, (b) longitudinal section 24 hours after oviposition, (c) longitudinal section 48 hours after oviposition, and (d) whole egg after hatch.

Table 3.--Position of eggs of Monodontomerus dentipes (Dalman) in 10 cocoons of Neodiprion lecontei (Fitch)

	Position of eggs on host body or cocoon			Total
	Head	Thorax	Abdomen	
Body	3	12	26	41
Cocoon	12	19	10	41

Larval Development and Pupation

The number of instars of M. dentipes was determined by rearing 33 individuals from the egg stage through the beginning of the fourth instar on N. merkeli at 20° C. Cocoons of the host were exposed to adults of the parasite for 8 to 12 hours. Eggs of the parasite were removed from the cocoons and placed in separate gelatin capsules with prepupae of N. merkeli which had been coddled by immersing them in their cocoons in water at 90° C for 3 minutes. The parasite-host unit consisted then of one individual each of N. merkeli and M. dentipes. Each parasite-host unit was observed daily for ecdysis of the parasite. Parasites were measured daily to determine whether or not size and other morphological characteristics are dependable for distinguishing instars of M. dentipes. Cast skins of the larvae were examined with a microscope.

The larvae of M. dentipes molted three times prior to pupation. They were observed feeding in all instars. During the final instar, there was a nonfeeding period before pupation.

All instars of M. dentipes are white, opaque, and vermiform, lacking true appendages. They are covered with long, hair-like setae which are perpendicular to the body and taper toward the ends, especially in later instars. The setae are somewhat functional in adhering to the host; in later instars, they assist in locomotion. The later instars also have pad-like callouses on the ventral side of the body, presumably useful for moving about.

The first instar of M. dentipes has only a few setae per segment, arranged roughly in a single row around each segment with the exception of the terminal segments (fig. 7). The setae are approximately 0.10 mm long. The mean length (mm) of live larvae of M. dentipes on the day of hatch was 0.441 $\pm$ 0.036 SD (15); the mean width at the widest point, 0.168 $\pm$ 0.014 SD (15); and the mean width of the head capsule at the widest point, 0.091 $\pm$ 0.017 SD (15). All dimensions increased on the second day (fig. 8). By the third day from hatch, many of the larvae had molted. The mean duration of the first stadium was 2.27 $\pm$ 0.704 SD (15) days at 20° C.

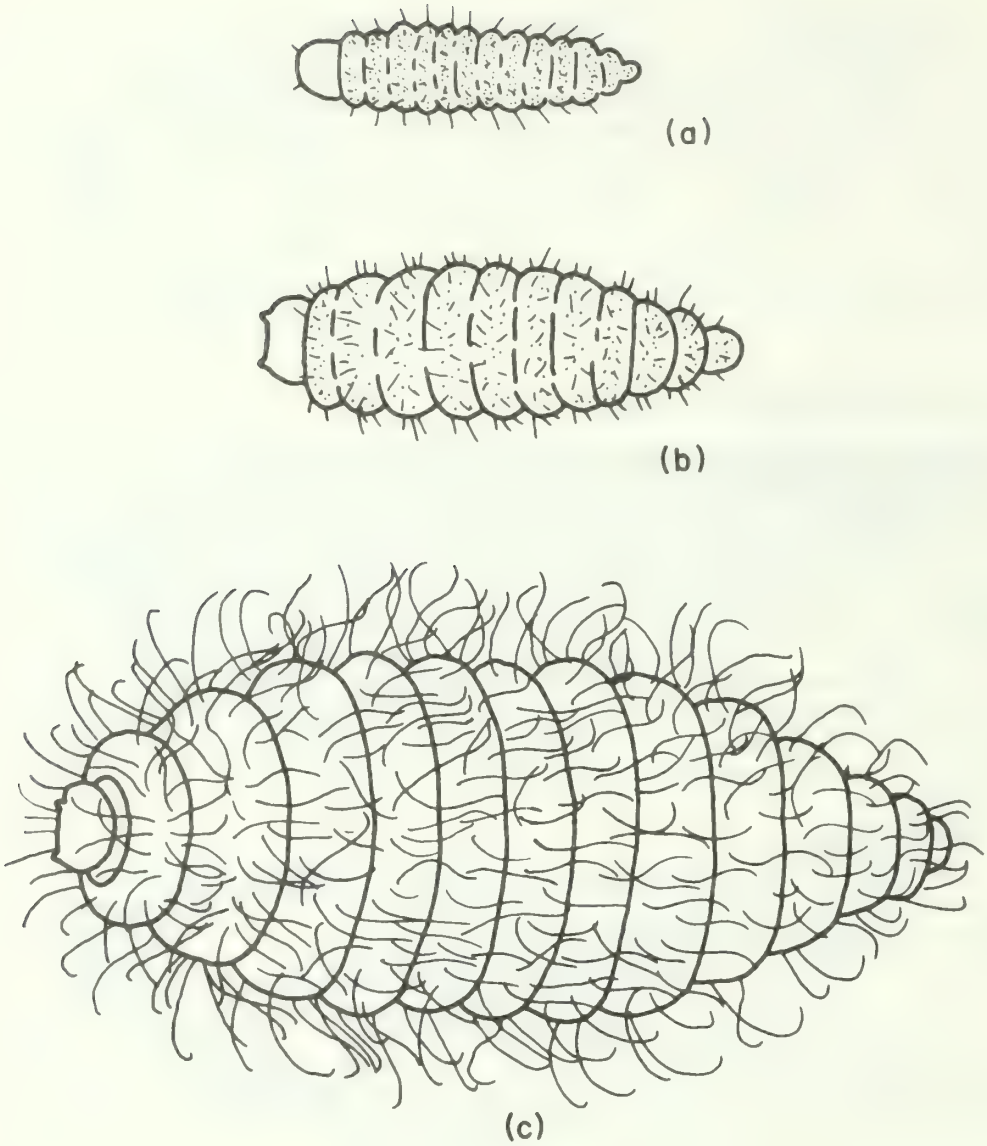

Figure 7.--Three of the four instars of Monodontomerus dentipes (Dalman): (a) first instar, (b) second instar, and (c) fourth instar.

The setae on the second instar are longer than on the first instar (fig. 7), and from some aspects the larvae appear to have roughly two rows of the longer setae per segment. However, it is difficult to distinguish the two instars on this basis alone. The second instars had a mean length (mm) of 0.939 $\pm$ 0.113 SD (14), a mean width of 0.279 $\pm$ 0.042 SD (14), and a mean head capsule width of 0.161 $\pm$ 0.040 SD (14). Although all three dimensions of seven larvae in the first stadium and eight in the second measured in the same day were found to be significantly different, the values overlapped.[7] The mean dimensions of each instar also fluctuated daily (fig. 8). Thus, size alone is not a reliable characteristic for separating first and second instars. The mean duration (days) of the second stadium was 1.09 $\pm$ 0.539 SD (11).

[7] t = 3.3675**; df = 13.

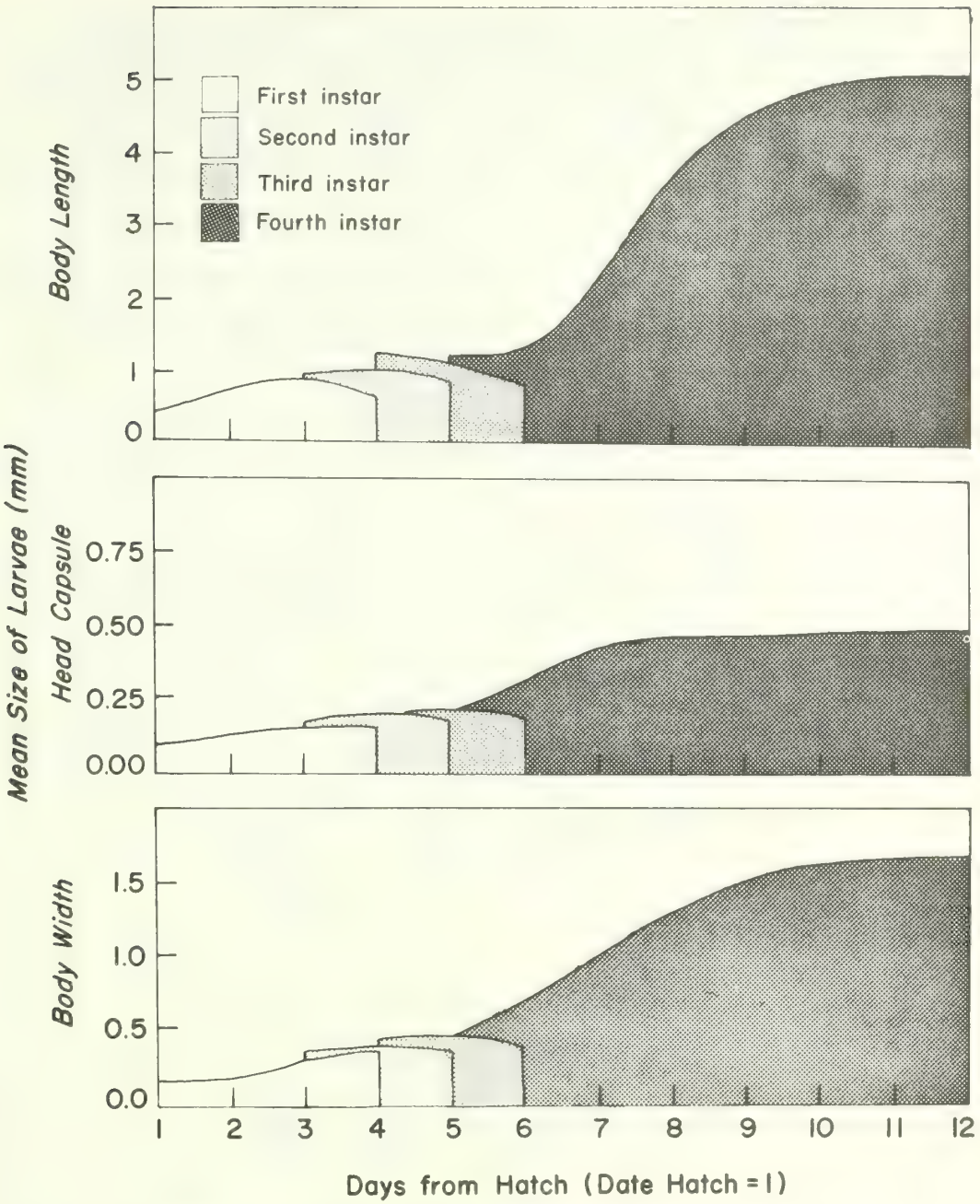

Figure 8.--Growth of the larvae of Monodontomerus dentipes (Dalman) on the host Neodiprion merkeli Ross at 20° C.

The third instar of M. dentipes is similar to the second except that it is slightly larger. On the first day of the third stadium, the mean length (mm) of the larvae was 1.30 ± 0.074 SD (6); the mean width, 0.34 ± 0.054 SD (6); and the mean head capsule width, 0.192 ± 0.029 SD (6). The mean duration (days) of the third stadium was 1.00 ± 0.58 SD (7) for the surviving larvae of 15 which hatched out originally.

The fourth instar of M. dentipes has many dense, long setae which often have hooked ends. Immediately after the third molt, these may be somewhat longer on the ventral side of the body than on the dorsal side. The setae appear to increase in length and density as the fourth instar grows older. The mean length (mm) of fully fed larvae in the fourth stadium was 3.284 ± 0.408 SD (10); the mean width, 1.086 ± 0.111 SD (10); and the mean head capsule width, 0.473 ± 0.024 SD (10). However, all of these measurements increased during the instar from the size just after the third molt. The duration of the fourth instar was not determined.

Although size of the larvae and number and length of the setae are helpful in recognizing the instars of M. dentipes, the only positive way for distinguishing all but the late fourth instar is to retrieve cast larval skins of the earlier instars.

If the insect diapauses, it occurs in the fourth instar. Gradual visible changes in the segmentation of the larva lead to formation of the pupa and shedding of the fourth instar larval skin. The pupa of M. dentipes is at first cream-colored. It begins to darken around the eyes and wings. Then, the entire insect turns black, and later, metallic black. The integument hardens as the pupa matures. The male and female pupae of M. dentipes are easily distinguished by the ovipositor sheath on the female (fig. 9).

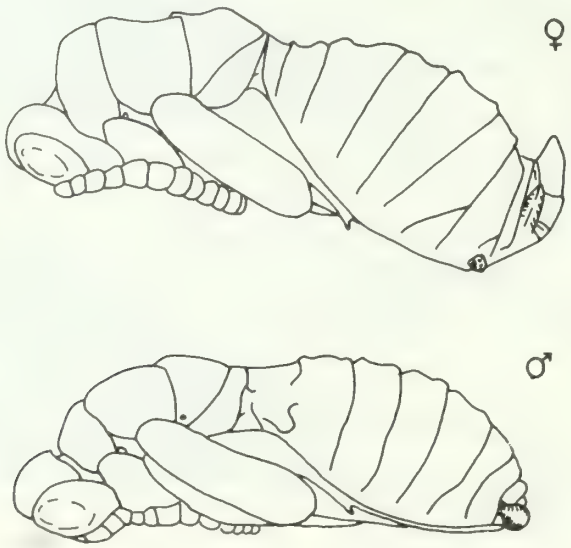

Figure 9.--The female and male pupae of Monodontomerus dentipes (Dalman).

EMERGENCE

Duration of Parasite Emergence from Individual Host Cocoons

During the laboratory rearings of M. dentipes, 185 cocoons each of N. lecontei and N. excitans were returned to gelatin capsules in which parasites had been reared. The host cocoons were re-examined daily for a month to determine the duration of emergence of M. dentipes from individual cocoons.

The duration of emergence of all M. dentipes from individual cocoons of N. excitans was shorter than the same period for N. lecontei (table 4). The longest period in which M. dentipes emerged from individual cocoons of N. excitans was 11 days, while that for N. lecontei was 12 days. Emergence of all parasites in 95.68 percent of N. excitans occurred within one day. However, all M. dentipes emerged in one day from only 85.95 percent of the N. lecontei cocoons.

The Pattern of Emergence in Laboratory Rearings

Although M. dentipes from the same host cocoon generally emerged on the same day (table 4), individuals reared on different host cocoons often differed greatly in their development time. The number of days from the egg stage to emergence varied greatly, even among host cocoons attacked by M. dentipes on the same day by the same females. On both N. lecontei and N. excitans, development time for M. dentipes ranged from about 15 to 250 days.

Table 4.--The duration of emergence of Monodontomerus dentipes (Dalman) from 185 individual cocoons each of Neodiprion lecontei (Fitch) and Neodiprion excitans Rohwer

Days after initial emergence	Host cocoons from which all M. dentipes had emerged	
	N. lecontei	N. excitans
	- - - - - - - - Percent - - - - - - - -	
0	85.95	95.68
1	90.27	97.84
2	94.05	98.38
3	94.59	98.38
4	95.14	98.38
5	96.76	99.46
6	97.30	99.46
7	98.38	99.46
8	99.46	99.46
9	99.46	99.46
10	99.46	100.00
11	100.00	--

A scatter-diagram of development time (from oviposition to the date of initial emergence from each cocoon) simulates emergence of the parasite on the laboratory hosts, N. excitans (fig. 10) and N. lecontei (figs. 11 and 12). Cocoons of N. excitans were used as hosts from May 1969 through March 1970. Those of N. lecontei were used from May to October 1969, and from June through December 1970. Use of unsuitable host cocoons (dead, in advanced stages of development, or infected by fungi) resulted in a lack of data for some months. However, the points on the scatter-diagrams occur in an orderly fashion. A large portion of the points representing emergence of M. dentipes from individual host cocoons occurred parallel to the x-axis (the month in which oviposition occurred) at about 40 days development time. The remaining points occurred in slanting lines parallel to each other, with their slopes equal approximately to minus one. Emergence appears to be cyclic at intervals of about 6 months in the laboratory.

Another view of the pattern of emergence of M. dentipes is obtained by plotting the percentage-frequency of host cocoons which produced parasites in a given time interval against the date of oviposition for the 1970 general rearing (fig. 13). Development times for M. dentipes on N. excitans and N. lecontei were divided into 26 time intervals of 10 days each. Interval I contained all those cocoons which produced adults of M. dentipes in one to 10 days from the date of oviposition. Interval II contained those cocoons which produced adults of M. dentipes in 11 to 20 days; Interval III, in 21 to 30 days; ... ; and Interval XXVI, in 251 to 260 days. The frequency of cocoons grouped into each development time interval was converted into the percentage of the total number of cocoons in all 26 development time intervals. By this conversion into percentages, the development time on the two host species could be compared. Using the three-class moving average weighted 1:2:1, which smooths irregularities from fluctuations (Croxton and Cowden 1955), a graphic representation of the development time of M. dentipes relative to the time of oviposition was obtained.

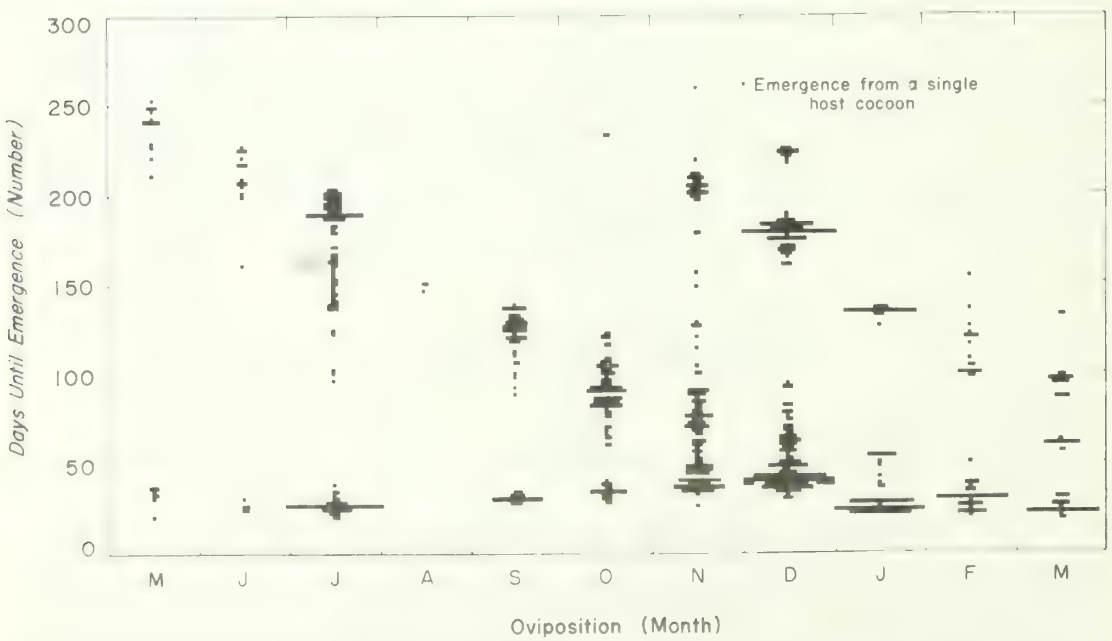

Figure 10.--Emergence of Monodontomerus dentipes (Dalman) from cocoons of Neodiprion excitans Rohwer parasitized from May 1969 through March 1970.

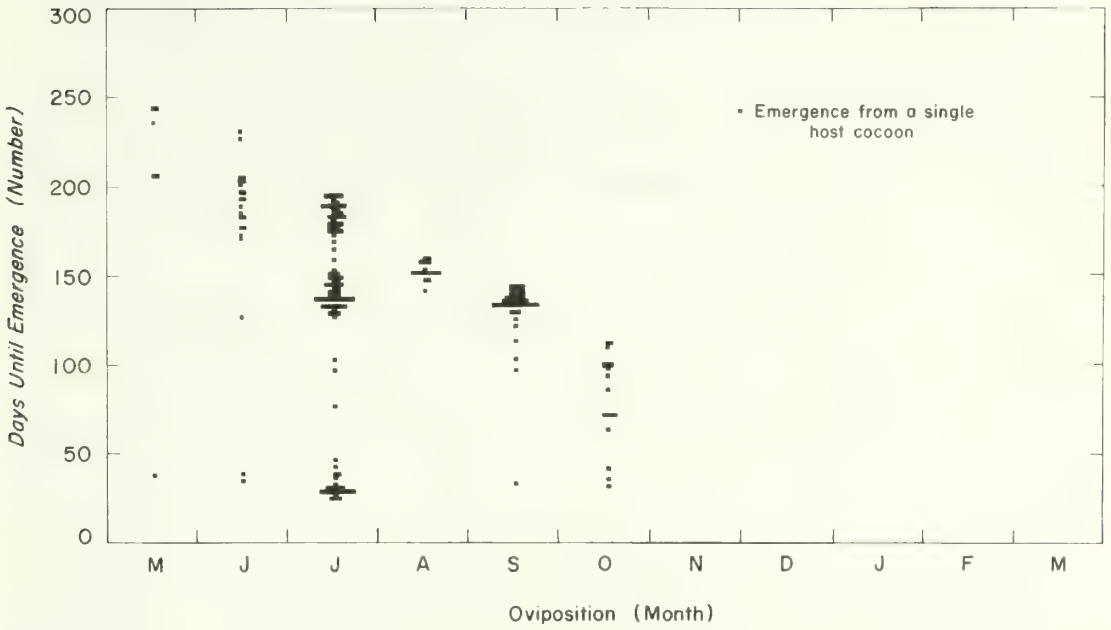

Figure 11.--Emergence of Monodontomerus dentipes (Dalman) from cocoons of Neodiprion lecontei (Fitch) parasitized from May through October 1969.

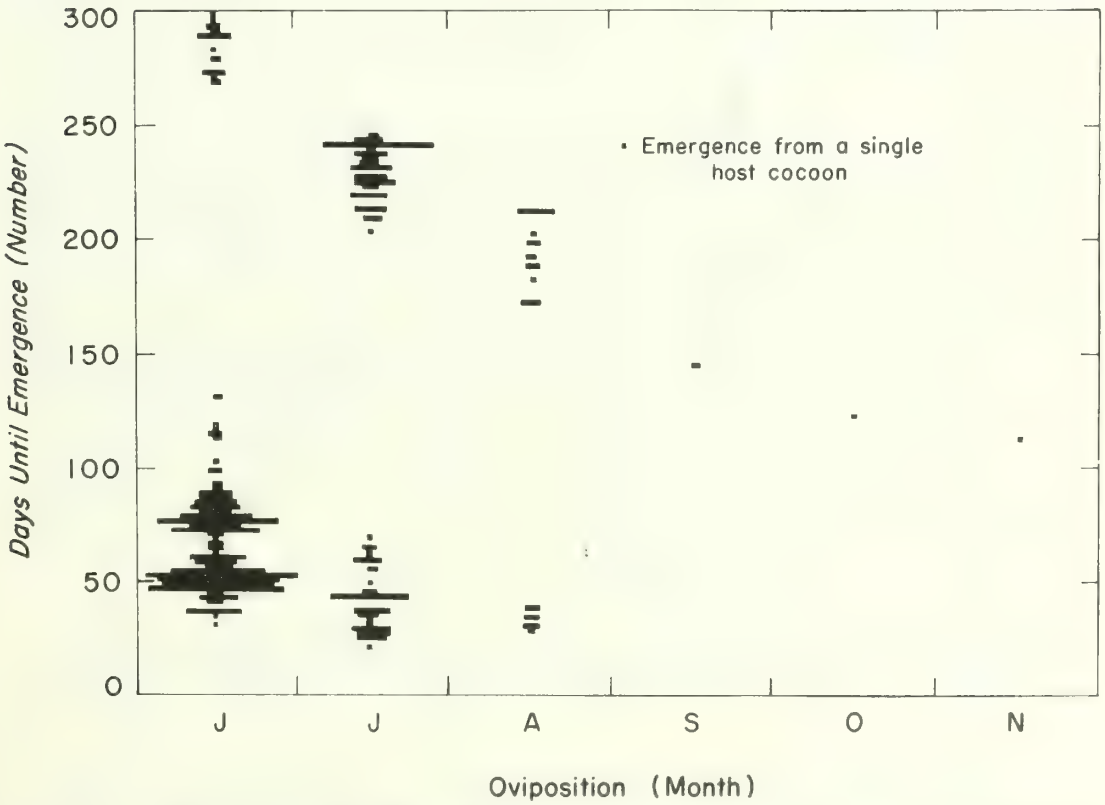

Figure 12.--Emergence of Monodontomerus dentipes (Dalman) from cocoons of Neodiprion lecontei (Fitch) parasitized from June through November 1970.

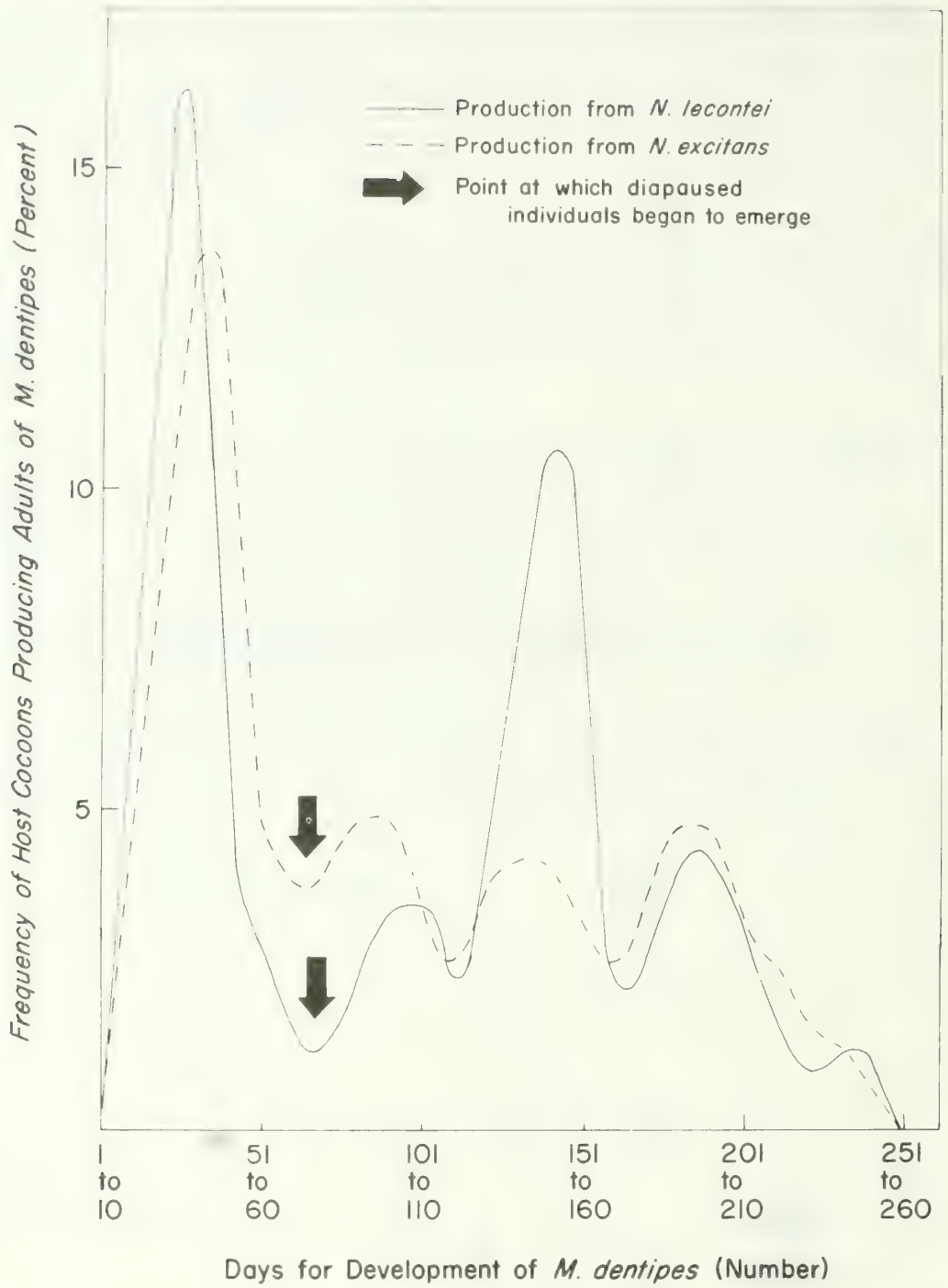

Figure 13.--Percentage-frequency of development time of Monodontomerus dentipes (Dalman) on cocoons of Neodiprion lecontei (Fitch) and Neodiprion excitans Rohwer in the 1970 general rearing.

Peaks in the percentage-frequency of host cocoons producing adults of M. dentipes occurred at 21 to 40 days development time for both host species. Additional production on both hosts resulted in smaller peaks at 71 to 100, 131, to 140, and 171 to 190 days after oviposition. All parasite production in 1970 occurred within 250 days of oviposition.

Both approaches for analyzing data from the laboratory rearings of M. dentipes indicate that some biological phenomenon operates during the development of the parasite which causes some to emerge from their host cocoons in much shorter periods than others. Neodiprion sawflies exhibit a similar compensatory mechanism which allows for synchronous emergence for individuals which spun cocoons at different times (Lyons and Griffiths 1962). The emergence of M. dentipes, parasitic on these sawflies, could reflect the condition of the host or parallel the situation, independent of the host.[8]

Effects of Rearing Temperature on Diapause in M. dentipes

Diapause of M. dentipes complicated laboratory rearing by lowering the predictability of emergence. Therefore, 525 cocoons of N. lecontei, exposed overnight to mated adults of M. dentipes, were reared at 10°, 15°, 20°, 25°, and 30° C to estimate the percentage of cocoons which could be expected to produce dispaused parasites at those temperatures. Three replicates of 35 "parasitized" cocoons each were held at each of the five temperatures for 60 days and at room temperature thereafter. Any parasites which emerged within the first 60 days were assumed to have developed directly, without diapausing. Those M. dentipes which emerged subsequent to removal of the host cocoons to room temperature were assumed to have diapaused.

At the extreme temperatures, 10° and 30° C, fewest cocoons produced parasites (table 5). At 10° C, parasites diapaused in all of the 17 cocoons which produced adults of M. dentipes from the three replicates. At 30° C, only one cocoon produced adults of the parasite and emergence occurred within 60 days of oviposition, i.e., the parasites developed without diapausing.

More cocoons produced parasites at 15°, 20°, and 25° C. However, only 30 of the 105 host cocoons held at 15° C, 26 of those held at 20° C, and 25 of those held at 25° C produced adults of M. dentipes. All of the parasites which emerged at 15° C had diapaused. M. dentipes from seven host cocoons at 20° C and five cocoons at 25° C diapaused.

Table 5.--Percentage of Monodontomerus dentipes (Dalman) which diapaused on the host Neodiprion lecontei (Fitch) at 10°, 15°, 20°, 25°, and 30° C. Three replicates of 35 host cocoons each were exposed to M. dentipes adults overnight and held at the indicated temperatures for 60 days and at room temperature thereafter

Temperature (°C)	Cocoons producing parasites		
	Total	Diapaused	Percent of total
10	17	17	100.0
15	30	30	100.0
20	26	7	26.9
25	25	5	20.0
30	1	0	.0

[8] Wilkinson, R. C. 1973. Personal communication. Univ. Fla. at Gainesville.

The optimum temperatures for rearing M. dentipes directly, i.e., without diapause, appear to be 20° to 25° C. At these temperatures, only a few cocoons produced parasites that diapaused. At the only higher temperature tested, 30° C, only one cocoon produced parasites.

Effects of Diapause in M. dentipes on Development Time of the Next Generation

Adults of M. dentipes which emerged in 1970 were maintained in two separate colonies: individuals which had diapaused, and those which had not. Using the time to initial emergence of M. dentipes from individual cocoons of N. lecontei, mean development time of the parasites from diapaused and non-diapaused parents was compared (table 6). First, the mean development time of non-diapaused M. dentipes from 97 host cocoons exposed to non-diapaused parents of the parasites was compared, by a t test, to that for non-diapaused M. dentipes from 110 host cocoons exposed to diapaused parents. Secondly, the mean development time of diapaused M. dentipes from 121 host cocoons exposed to non-diapaused parents was compared, also by a t test, to the development time of parasites from 143 host cocoons exposed to diapaused parents. There were highly significant differences in the development time of parasites from diapaused and non-diapaused parents, regardless of whether the F_1 generation of M. dentipes had diapaused. Among non-diapaused parasites, the development time for individuals from diapaused parents was longer (48.78 days) than for those from non-diapaused parents (40.02 days). Conversely, among diapaused F_1 parasites, the mean development time for individuals with diapaused parents was shorter (130.63 days) than for those with non-diapaused parents (200.60 days).

Table 6.--Mean development time in days of non-diapaused and diapaused Monodontomerus dentipes (Dalman). Numbers in parentheses indicate the number of Neodiprion lecontei (Fitch) cocoons represented in each case

Parents	F_1	
	Non-diapaused	Diapaused
Non-diapaused	40.02 (97)	200.60 (121)
Diapaused	48.78 (110)	130.63 (143)
Significant effect of parent diapause on development time of F_1	Increase[1]	Decrease[2]

[1] $t = 8.296^{**}$; df = 205.
[2] $t = 7.764^{**}$; df = 262.

SUMMARY AND DISCUSSION

M. dentipes was reared on cocoons of N. lecontei, N. excitans, and N. merkeli in the laboratory. Adults of the parasite mated immediately after emergence from the host cocoon and oviposited readily in the laboratory. Colonies could be maintained as long as suitable host material was available.

Aqueous honey and raisins were readily accepted foods of adult females of M. dentipes. The parasites were not observed feeding on clipped pine needle fascicles or prepupae of N. lecontei. This suggests that M. dentipes may favor flower nectar or honeydew over pine needle juices and sawfly prepupae in the field. Presumably, sawfly prepupae would not be an important food source for adults of M. dentipes, even though they are the exclusive food source of the larvae. In this respect, the success of biological control programs in which M. dentipes is released into a sawfly infestation would depend on the availability of some food source for the adults other than sawfly prepupae or pine needles.

Feeding incidences of adults increased during the afternoons due mainly to increased feedings on honey-water. Generally, temperatures in the laboratory were higher, and humidities lower, during the afternoons. Increased feedings on such an aqueous solution as 10 percent honey-water would provide moisture to replace moisture lost to ambient conditions. M. dentipes would also be expected to feed more in the field during the afternoons, but the increased feedings during periods of higher temperatures also suggest that the parasite may tolerate increases in temperature and decreases in humidity as long as there is available moisture. In releasing M. dentipes, which thrives in Canada and Northeastern United States, into more southeastern climates, moist food sources, and possibly the availability of aphid honeydew, could be critical factors in the parasite's ability to meet the demands of higher temperatures and lower humidities. Even though the Southeastern United States, and especially Florida, is considered humid, there are periods when the humidity is low.

The longevity of adult females of M. dentipes (29.11 days in North Carolina) was very close to that (30.6 days in Wisconsin) found by Mertins (1967) for individuals reared in the laboratory on sugar-water. Survival declined rapidly after 15 days, but some females lived 40 days. The survivorship data have both laboratory and field application. In the laboratory, experiments with adult females should be planned, if possible, to coincide with the first 2 weeks of the adult life cycle. If the experiment is to last longer than 2 weeks, sufficient individuals should be used to insure that enough will survive to provide sufficient data. For field release, the optimum time to release females appears to be immediately after emergence from the host cocoon. In the laboratory, most oviposition occurred within the first 2 weeks after parasites emerged. If the survivorship in the field is similar to that obtained in the laboratory, the population of released individuals will be on the decline. For this reason, the time of release of M. dentipes must be coordinated with the development of the intended sawfly host. The parasite should not be released more than a week or so before the sawflies cocoon or M. dentipes will not find a suitable host. The sawfly should also be cocooned in order for M. dentipes to attack it. The third or fourth day following emergence of M. dentipes is believed the optimum time of release, since at that time the preoviposition time would be over and the adults would not have time to scatter before ovipositing.

The oviposition behavior of M. dentipes consisted of searching for the host cocoon, immobilization of the host prepupa, and deposition of eggs. These processes were repeated several times on the same host cocoon, and often several females oviposited on the same host cocoon. In the laboratory, superparasitism may be advantageous to a point, but the number of individuals of M. dentipes which can develop on one host is limited. When too many eggs of the parasite are deposited in a host cocoon, starvation or dwarfing results. In the field, superparasitism would not be as likely as in the laboratory since the ratio of adult parasites to host cocoons would be lower.

Suitable host cocoons are costly and time consuming to obtain. They can be preserved in laboratory rearings by offering them to females of M. dentipes only in periods when egg production is maximum. In the laboratory, peaks in egg production per female and the percentage of females ovipositing both occurred at 4 to 5 and 13 to 16 days after emergence from the host cocoon. The mean preoviposition time was about 7 days, although some individuals began ovipositing as early as 3 days after emergence. For efficiency, host cocoons should be offered to the M. dentipes from about the fourth to the twentieth day after emergence from the host cocoon.

The eggs of M. dentipes were fairly evenly distributed over the host body and the inside wall of the host cocoon, indicating that the ovipositing female of M. dentipes is probably not attracted to either end of the host cocoon, at least on the basis of external appearance. A higher percentage of the total eggs was found in the posterior end of the cocoons and on the abdomen of the host prepupae than anywhere else. J. W. Mertins[9] has observed prepupae of D. similis with numbers of M. dentipes eggs crushed in the mandibles, so there may be some disadvantage in oviposition at the head end. A trend may be indicated, but the abdomen comprises the major part of the host body and a greater number of eggs would be expected to be oviposited there, even if oviposition sites were random. In later experiments, eggs were placed with host prepupae into No. 2 size gelatin capsules which are larger than the largest host cocoons used, those of N. lecontei. Although a few apparently starved, most developed. Presumably, in the more confined space of a host cocoon, the parasite larva would have no trouble reaching the host body from any position in the cocoon.

The four instars of M. dentipes were distinguished from each other by their size and by the length and arrangement of their setae. Although these characteristics are difficult to use, they are the only practical means available. Distinguishing the sexes of the pupae was simple; the ovipositor sheath of the female is unmistakable.

All of the adults of M. dentipes from the same host cocoon emerged within 11 days of each other on N. excitans and 12 days on N. lecontei. Most emerged on the same day as others from the same cocoon, and if any parasites in a given host cocoon diapaused, all diapaused, even though the individuals were not necessarily progeny of the same female. Since males generally emerge prior to the females and have a shorter adult lifespan, this virtually simultaneous emergence by parasites tends to insure mating of the females. Females which emerge much later than the males would tend to produce infertile eggs. In this instance, synchronized emergence apparently works against parthenogenesis.

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[9] Mertins, J. W. 1973. Personal communication. Univ. Wis. at Madison.

The pattern of emergence from different host cocoons indicated that some individuals of M. dentipes diapaused. Parasites emerged from some cocoons of both hosts, N. lecontei and N. excitans, about 40 days after oviposition. Emergence of parasites from the remaining cocoons was delayed, presumably by diapause. The percentage-frequency of host cocoons producing adults of M. dentipes was highest at 21 to 40 days after oviposition on both host species. Lower peaks of the percentage-frequency of cocoons of N. excitans and N. lecontei producing adults of M. dentipes occurred at 71 to 100, 131 to 140, and 171 to 190 days after oviposition. However, emergence of practically all diapaused individuals of M. dentipes occurred in January 1970, June 1970, and January 1971, at approximately 6-month intervals.

Temperature and whether or not parents had diapaused were two of the factors which might have affected development time of M. dentipes, although there are others which should be examined. When reared at different temperatures, more host cocoons exposed to M. dentipes produced adults of the parasite at 15°, 20°, and 25° C than at 10° and 30° C. Since only one individual of M. dentipes emerged at 30° C, the parasite probably would not be successful in areas where the average daily temperature remains above 30° C for long periods. At rearing temperatures of 15° C and lower, all M. dentipes diapaused. In the Southeastern United States, M. dentipes should have more generations each year than it does in Wisconsin due to milder temperatures. As long as suitable host material is available, a released population of M. dentipes should build up rapidly. Unexplainable collapses in sawfly populations, which are common in the Southeast, might complicate the establishment of M. dentipes, however. If the only host sawfly species disappears from an area, then the parasite would also disappear and would have to be reintroduced should the sawfly reappear.

Development time of M. dentipes influenced diapause in the progeny (F_1). Diapause in the parents increased the development time for non-diapausing F_1 parasites and decreased it for diapausing F_1 parasites. Thus, diapause in the parent generation narrows the emergence time of the F_1 generation. The difference in development time for diapausing and non-diapausing F_1 individuals is less when their parents diapaused than when they developed without diapause. Thus, diapause in one generation would ten to insure synchrony of emergence of the next generation. Synchronous emergence would facilitate mating and survival of the species.

LITERATURE CITED

Croxton, F. E., and D. J. Cowden
1955. Applied general statistics. 843 p. Prentice-Hall, Inc., New York.

Fedde, Vicki H.
1974. Current knowledge of Monodontomerus dentipes (Dalman), a cocoon parasite of pine sawflies. USDA For. Serv. Gen. Tech. Rep. SE-6, 19 p. Southeast. For. Exp. Stn., Asheville, N.C.

Lyons, L. A., and K. J. Griffiths
1962. Observations on the development of Neodiprion sertifer (Geoff.) within the cocoon (Hymenoptera: Diprionidae). Can. Entomol. 94:994-1001.

Mertins, J. W.
1967. The insect parasites of the introduced pine sawfly, Diprion similis (Hartig) (Hymenoptera: Diprionidae), in Wisconsin. Master's Thesis, Univ. Wis., 119 p.

Mertins, J. W., and H. C. Coppel
1971. The insect parasites of the introduced pine sawfly, Diprion similis (Hartig) (Hymenoptera: Diprionidae), in Wisconsin, with keys to the adults and mature larval remains. Wis. Acad. Sci., Arts, & Lett. 59:127-168.

Morris, K. R. S., E. Cameron, and W. F. Jepson
1937. The insect parasites of the spruce sawfly (Diprion polytomum Htg.) in Europe. Bull. Entomol. Res. 28:341-393.

Nicholls, C. F.
1963. Some entomological equipment. Can. Dep. Agric. Res. Inst. Inf. Bull. 2, 85 p.

Fedde, Vicki H.
1975. Development and emergence of Monodontomerus dentipes (Dalman), a parasite of pine sawflies. USDA For. Serv. Res. Pap. SE-132, 24 p. Southeast. For. Exp. Stn., Asheville, N. C.

Monodontomerus dentipes (Dalman) was reared in the laboratory on cocoons of Neodiprion lecontei (Fitch), N. excitans Rohwer, and N. merkeli Ross. During development, the cocoon parasite had an egg stage, four instars, a pupal stage, and an adult stage. Eggs were distributed throughout the host cocoon on the prepupa and on the inside walls of the cocoon. They took three days to hatch. The four instars were distinguished by size and the relative number of setae. Duration of final larval stadium varied greatly, depending on whether the individual diapaused. Male and female pupae were distinguished by a dorsally turned ovipositor sheath on the female. Longevity of mated females of M. dentipes was independent of density and mean survival was 29.11 days.

Adults mated immediately after emergence from the host cocoon. Mean preoviposition period was 6.63 days. Egg production was negligible past the 25th day.

Development times for all M. dentipes from the same host cocoon were similar. Emergence varied from 15 to 250 days after oviposition. Most adults of M. dentipes emerged about 40 days after oviposition. Those which diapaused took more than 60 days to develop. At constant temperatures of 15° C or less, all M. dentipes which developed, diapaused. Diapause of the parent generation of M. dentipes increased the development time of non-diapausing F_1 individuals and decreased the development time of diapausing F_1 individuals.

Fedde, Vicki H.
1975. Development and emergence of Monodontomerus dentipes (Dalman), a parasite of pine sawflies. USDA For. Serv. Res. Pap. SE-132, 24 p. Southeast. For. Exp. Stn., Asheville, N. C.

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USDA Forest Service Research Paper SE-133 June 1975

Slash Pine: Some Intriguing Growth and Yield Relationships

by

Frank A. Bennett

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Slash Pine: Some Intriguing Growth and Yield Relationships

by

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The negative correlation between height growth and stand density of natural slash pine has been documented by Collins (1967). Indications of the same correlation in young old-field plantations of slash pine were also pointed out some years ago by Harms and Collins (1965). The relationship between site and basal area growth of pine species has evoked considerable discussion without definitive conclusions, and expected responses from site preparation and other cultural treatments are the subject of much speculation. This paper attempts to explore fully the relationships and interactions between height and density and between basal area growth and site of slash pine, to explain their significance in management programs, and to point out some practical aspects about growth responses one can expect from cultural treatments.

THE HEIGHT-DENSITY RELATIONSHIP

Natural Stands

First, an updating of the report by Collins (1967) on height growth and stand density of natural slash pine is appropriate. In the spring of 1951, three treatments were imposed on dense stands of natural slash pine which had seeded two fields in the fall of 1947. The treatments were control, thinning to clumps of 6 to 8 trees at 10- by 10-foot spacing (center to center), and thinning to a single tree at 10- by 10-foot spacing. Four replicates of each treatment were established. At age 17 (14 years after treatment), dominant height in the single-tree plots was 10.6 feet greater than in the control plots and 4 feet greater than in the clumps (Collins 1967).

At age 23 (20 years after treatment), treatment averages are as follows:

	Surviving trees (number)	Mean dominant height (feet)
Control	3,978	38.6
Clump	1,298	48.5
Single-tree	336	54.3

A regression of the form

$$\text{Log height} = a_0 + a_1 \text{ (number of trees per acre)} \quad (1)$$

explained 92 percent of the variation in dominant height among the 12 plots.

The height-density relationship in natural stands was further tested by including a density variable in a height-age analysis involving 174 unthinned plots ranging from 17 to 63 years of age and from 88 to 1,800 trees per acre. The following equation resulted:

$$\text{Log height} = 2.00627 - \frac{5.4215}{\text{age}} - 0.00004643 \text{ (number of trees per acre)} \quad (2)$$

where log = common logarithm. The density variable was significant at the 1-percent level.

Plantations

In the slash pine plantations with various spacings as originally reported by Harms and Collins (1965), dominant heights at age 22 are also influenced by stand density, with lower densities resulting in greater heights (table 1). A regression of the form

$$\text{Height} = a_0 + a_1 \text{ (number of trees per acre)} \quad (3)$$

explained 75 percent of the variation in dominant height. The linear form of both the dependent and independent variable was the most effective expression.

Table 1.--Dominant height of planted slash pine at age 22 as affected by stand density

Spacing (feet)	Block A		Block B		Mean	
	Surviving trees	Dominant height	Surviving trees	Dominant height	Surviving trees	Dominant height
	Number	Feet	Number	Feet	Number	Feet
6 by 6	820	58.1	867	51.9	843	55.0
6 by 8	624	58.2	581	58.5	602	58.3
5 by 10	630	60.2	587	56.3	608	58.2
8 by 8	558	57.8	494	59.6	526	58.7
6 by 12	464	59.2	411	56.7	437	57.9
10 by 10	361	61.6	312	64.1	336	62.8
$7\frac{1}{2}$ by 15	325	62.8	333	61.8	329	62.3
15 by 15	164	63.5	164	63.1	164	63.3

The observed heights indicate some site variation among plots within spacings. To determine if site was better for the wider spacings, dominant heights for all plots were adjusted on the basis of number of surviving trees per acre (164) for the 15- by 15-foot spacing by the usual technique:

$$\text{Adjusted } \bar{Y}_i = \bar{Y}_i - b(\bar{X}_i - \bar{X}) \qquad (4)$$

where $\bar{Y}_i$ = unadjusted mean for treatment i, $\bar{X}_i$ = mean of independent variable for treatment i, $\bar{X}$ = mean x for the 15- by 15-foot spacing, and b = regression coefficient. Adjusted dominant heights for the various spacings are as follows:

	Block A (feet)	Block B (feet)	Mean (feet)
6 by 6	66.6	61.0	63.8
6 by 8	64.2	63.9	64.1
5 by 10	66.3	61.8	64.0
8 by 8	62.9	63.9	63.4
6 by 12	63.1	60.0	61.5
10 by 10	64.2	66.0	65.1
$7\frac{1}{2}$ by 15	64.9	64.0	64.5
15 by 15	63.5	63.1	63.3

After adjustment for density effect, it is obvious that site was not better for the wider spacings and that most of the observed height difference is attributable to density effect. In fact, the total effect of density can be expressed as the difference between the observed mean height for the 15- by 15-foot spacing and the adjusted mean height for the particular spacing involved (table 2). For example, an increase of 679 surviving trees per acre (15- by 15-foot vs. 6- by 6-foot spacing) reduced dominant height by 8.8 feet, after adjustment for a small site difference that favored the narrower spacing.

Practical Significance

What is the practical significance of this density-height interaction in relation to site index?[1] Must we have site index curves by density classes (within a site class) to apply the site index concept properly in management operations? Not necessarily. Suppose we collect height-

[1] Significance of the interaction in relation to precommercial thinning, merchantable wood yield, and management in general was covered by Collins (1967) and will be further covered by Earle P. Jones of the Southeastern Station in a forthcoming Research Paper.

Table 2.--Effect of density on dominant height of planted slash pine at age 22 after adjustment for site differences

Spacing to be compared with 15 by 15 (feet)	Height difference[1]	Adjustment for site difference[2]	Density effect[3]
		Feet	
6 by 6	-0.5	55.0 - 0.5 = 54.5	63.3 - 54.5 = 8.8
6 by 8	-0.8	58.3 - 0.8 = 57.5	63.3 - 57.5 = 5.8
5 by 10	-0.7	58.2 - 0.7 = 57.5	63.3 - 57.5 = 5.8
8 by 8	-0.1	58.7 - 0.1 = 58.6	63.3 - 58.6 = 4.7
6 by 12	1.8	57.9 + 1.8 = 59.7	63.3 - 59.7 = 3.6
10 by 10	-1.8	62.8 - 1.8 = 61.0	63.3 - 61.0 = 2.3
$7\frac{1}{2}$ by 15	-1.2	62.3 - 1.2 = 61.1	63.3 - 61.1 = 2.2

[1] Observed mean height for the 15- by 15-foot spacing minus the adjusted mean height for the given spacing.
[2] Observed mean height for the given spacing plus the adjusted factor.
[3] Observed mean height for the 15- by 15-foot spacing minus the adjusted mean height for the given spacing.

age data for the construction of site index curves and cover a range of densities (averaging 500 trees per acre) properly stratified across the available ranges of age and site; then we construct a height-age equation, e.g., Log height = $a_o + a_1 \frac{1}{age}$. This equation will produce site index curves reflecting the average density effect at any given age. Suppose we wish to apply such curves to two stands of the same age and the same soil and site conditions but with different densities: one with 150 trees per acre and the other with 800. Let us further assume that the site index, based on the average density of the sample from which the site index curves were constructed, is 80 (50-year basis). Now, when we apply the dominant heights of the two stands to the curves, one will produce a reading somewhere above the site 80 curve and the other a reading somewhere below, giving an automatic correction for density effect.

However, the effect of density on height may be a matter of concern in the comparison of yields for various density classes within a site class. As presently set up, yield tables do not give an exact comparison between density classes because site is held constant (within a site class) for a wide range of densities. On the basis of equation (2), the site adjustments necessary for exact yield comparisons among densities for natural slash pine could equal as much as 10 feet or more (table 3). These data illustrate that tables of yield posted by a wide range of basal area density classes within a site class actually reflect yields for successively higher site indexes. It should be understood that, because basal area increases as site increases, basal area cannot be substituted for number of trees per acre as a density measure in the height-age analysis from which the site index curves are derived. To demonstrate density effect on height, the density variable must be independent of site.

Table 3.--Comparison of slash pine site indexes (50-year basis) for 200 trees per acre with those for varying numbers of surviving trees per acre

50-year site index class: 200 trees per acre (feet)	Number of surviving trees per acre				
	400	600	800	1,000	1,200
	Site index (feet)				
60	58	57	56	55	54
70	68	67	66	65	63
80	78	77	75	73	72
90	88	86	84	82	81
100	98	96	94	92	90

As an aid in making exact yield comparisons for varying basal area densities in natural stands, the following equation, developed from measurements made on 174 unthinned, natural slash pine plots, may be used to determine the number of trees per acre associated with various combinations of age, site, and basal area density:

$$\text{Log } B = 1.52417 - \frac{6.74476}{\text{age}} - \frac{32.227}{\text{site}} + 0.45395 \text{ Log } N \qquad (5)$$

where B = basal area, N = number of trees per acre, and log = common logarithm. This regression removed 70 percent of the variation in basal area yield. To illustrate use of the equation, the numbers of trees per acre associated with various basal area yields at age 20 on site 100 are as follows:

Trees per acre (number)	Basal area yield (square feet per acre)
69	50
168	75
318	100
520	125
775	150
1,090	175

Taken individually, each of these basal area yields and the associated number of trees represent a yield for site 100; but if as a group they represent yields for site 100, then they represent different soil or site conditions. For example, if a given soil condition produces 50 square feet of basal area at age 20 from 69 trees and classifies as site 100, the same soil condition with 1,090 trees will represent site 91 and

produce less than 175 square feet of basal area. Hence, site adjustments are necessary if exact yield comparisons among density classes are desired within a site class.

The effect of density on the height of planted slash pine as illustrated in table 1 suggests that adjustments similar to those for natural stands will be needed if exact comparisons of yield for varying density classes are desired. For example, the 25-year site index for the 15- by 15-foot spacing is 68, the equivalent of a 50-year site 90 for natural stands. An increase in density of about 700 surviving trees per acre reduced the dominant height of planted pines by 8.8 feet at age 22. It is reasonable to expect this difference to hold at the index age of 25, resulting in a reduction in site index of about 9 feet. In comparison, an increase in density of 700 trees per acre for natural stands on site 90 (50-year basis) reduced site index by 7 feet at age 25, as calculated by equation (2).

To summarize, application of site index curves in management programs requires no adjustment for density effect; the curves are self-correcting. Adjustments are necessary only if exact yield comparisons within a site class for various density classes are desired.

BASAL AREA GROWTH AND SITE

As noted previously, reports on the relationship between basal area growth and site are conflicting, with results ranging from a weak positive correlation to a highly significant negative one (Simmons and Schnur 1937; Spurr 1952; Buckman 1962; Crowe 1967). It is difficult to reconcile this range in variation with respect to a specific growth relationship. Because of the strong positive effect of site on diameter and volume growth, it is also hard to rationalize a weak positive effect of site on basal area growth, much less a negative correlation between these two stand variables. Explanations offered by various authors for the seeming lack of correlation, or a negative one, between the two parameters include fluctuations in climate, insect attacks, inexact measurement techniques, imprecision of site index as a measure of site quality, and mortality.

Data derived from my work with slash pine have also indicated a negative correlation between basal area growth and site. A detailed inspection of my sample data revealed a logical explanation for this seemingly illogical result. The study design, one normally used in studies of growth and yield, required plots of the same residual basal area density on all sites within age classes. This requirement forced a strong negative correlation between number of trees per acre and site, and as a result little effect of site on basal area growth could be detected (table 4).

Table 4.--Average stocking levels and basal area growth in a study of stand density in slash pine

50-year site index (feet)	Plots	Trees per acre	Basal area stocking	Periodic annual basal area growth
	- - - Number - - -		- - - Square feet - - -	
60	3	547	107	2.053
70	26	460	89	2.415
80	58	372	90	2.117
90	28	278	99	2.120
100	5	266	108	2.128

As shown in table 4, growth was almost the same on sites 60 and 100, which had the same basal area stocking; but it was 13.5 percent greater on site 70 than on site 100, although basal area stocking was greater on the latter. Note, however, that site 60 had more than twice as many trees per acre as did site 100 and that site 70 averaged 1.73 times as many. The loss to mortality in number of trees per acre in this study was essentially the same on all sites. Basal area loss to mortality therefore increased as site increased, and this loss further diluted the effect of site on basal area growth. In fact, when basal area stocking is constant across site, such a pattern of mortality can cause a strong negative correlation between basal area growth and site. However, basal area growth, like diameter and volume growth, is strongly influenced by number of trees per acre; and when basal area stocking is held constant within age classes for all sites, the increase in number of trees per acre as site decreases masks the effect of site on basal area growth, even in the absence of mortality. This masking is clearly demonstrated by data on basal area yields of plantations as calculated from established diameter distributions (table 5).

The plantation data illustrate that with basal area stocking almost constant across site, basal area growth is essentially the same on all sites. However, the number of trees per acre associated with the basal area yields varies greatly.

Practical Significance

The existence of a weak positive correlation, or even a negative one, between basal area growth and site has no real significance in relation to stand management or study design. The point of concern is an understanding of what produces the particular relationship. For example,

Table 5.--Basal area yields for planted slash pine as calculated from established diameter distributions

Age (years)	25-year site index[1]			
	50(1,000)	60(600)	70(400)	80(300)
	- - - - - - - Basal area yield (square feet) - - - - - - -			
10	66	64	66	68
20	128	133	134	133
10-year growth	62	69	68	65
Annual growth	6.2	6.9	6.8	6.5

[1]Figures in parentheses represent number of trees per acre.

the negative correlation which occurred between these two variables in my study of stand density in slash pine does not invalidate the study results. All growth and yield results are valid for the stand conditions imposed by the study design. In research studies or stand management, the degree and type of correlation between basal area growth and site is determined by the density measure used and the pattern of mortality, if any. If number of trees per acre is the density variable, or if basal area stocking is reduced as site decreases, there will be a strong positive relationship; if basal area, stand density index (SDI), percent of height, stocking percent, or cubic volume stocking is employed and stocking is held constant across site within age classes, the correlation may range from weakly positive to strongly negative, depending upon the pattern of mortality and the data ranges covered in the study or stand conditions in the managed forest.

As stated, growth responses, both basal area and volume, will be a reflection of imposed stand conditions, and proper interpretation of results entails an understanding of the interactions of the stand parameters. With this understanding, a negative correlation between basal area growth and site is no longer an illogical biological relationship to be explained away by the researcher or forest manager, but a relationship to be accepted as representative of specific stand conditions.

EXPECTED RESPONSES TO CULTURAL TREATMENTS

There is much speculation on the increases one can expect in volume production from various cultural treatments, including the use of superior stock. One hears estimates of expected increases ranging as high as 400 percent. A careful analysis of growth and yield patterns for managed stands of natural slash pine may be useful in rationalizing expected responses.

Cubic volume yields for natural stands of slash pine at age 30 are presented in table 6. Analysis of these data indicates that the percentage increase in yield per unit increase in site is the same for all stocking levels. However, as site increases, the percentage increase in yield (and site) per unit increase in site goes down:

Increase from site--	Percent increase (yield)	(site)
60 to 70	33.6	16.7
70 to 80	24.3	14.3
80 to 90	18.4	12.5
90 to 100	14.5	11.1

Because of this relationship, successively greater increases in site as a result of cultural treatment will be required as site increases in order to realize a given percentage increase in yield (table 7).

Table 6.--Cubic volume yields for natural slash pine at age 30; adapted from Bennett (1970)

50-year site index (feet)	Basal area stocking (square feet)				
	50	75	100	125	150
	Cubic feet				
60	906	1,304	1,688	2,061	2,428
70	1,211	1,742	2,255	2,754	3,244
80	1,505	2,165	2,802	3,423	4,031
90	1,782	2,564	3,318	4,053	4,774
100	2,040	2,935	3,799	4,640	5,465

Table 7.--Site increases necessary to produce given percentage yield increases when basal area is the density measure

50-year site index (feet)	Site index increase required to increase yield by the following percentages--					
	25	50	75	100	125	150
	Feet					
60	8	15	22	31	40	50
70	10	21	33	47	63	75
80	14	29	46	64	85	--
90	18	38	60	82	--	--
100	22	47	76	--	--	--

To increase the cubic yield of site 70 by 50 percent through cultural means, including the use of superior stock, we must increase the site to 91 feet; to double the yield through intensive culture, the site must be increased to 117 feet. To increase the yield of site 80 by 50 percent would require an increase in site to 109 feet, and to increase it 100 percent would require an increase to 144 feet. These required site increases hold for all stocking levels and are based on the following assumptions: basal area stocking is not increased; tree form is not altered significantly as a result of intensive culture; the pattern of yield increase per unit increase in site as established for sites 60 through 100 will hold for sites above 100; and only merchantable stemwood is involved.

The data in table 7 apply when a given residual basal area stocking is constant across site. The illustration does not suggest that basal area stocking in managed stands should be the same in all sites. The example is given in this fashion because yields are usually tabulated by density classes that hold for all sites. If trees per acre is the density control, or basal area stocking varies with site, the data do not apply.

For example, equation (5) shows that if number of trees per acre is constant across site, the following ratios hold with respect to basal area yield:

	Site class
0.61	60
0.73	70
0.83	80
0.92	90
1.00	100

With basal area stockings based on these ratios, which would be the equivalent of using trees per acre as the density measure, it is obvious that yield increase per unit increase in site will be greater than when basal area is constant across site, for cubic volume yield is very highly correlated with basal area yield. Consequently, the increase in site index required to produce a given percentage increase in cubic yield (table 8) will be less than when basal area is constant across site (table 7). These required site increases rest on the same assumptions as those applying when basal area is the density control.

The difference between the two density measures in the required site increases for a given yield increase relates to the difference in cubic volume stocking associated with the two variables (table 9).

Table 8.--Site increases necessary to produce given percentage yield increases when trees per acre is the density measure

50-year site index (feet)	Site index increase required to increase yield by the following percentages--					
	25	50	75	100	125	150
	Feet					
60	5	10	15	19	23	27
70	7	13	19	26	32	38
80	9	18	27	36	45	54
90	12	23	37	50	62	--
100	14	30	46	63	--	--

Holding trees per acre constant across site results in an increasing basal area stocking as site increases, whereas holding basal area constant across site results in a reduction in number of trees per acre as site increases. Because cubic volume yield is a function of number of trees per acre as well as basal area, the negative correlation between number of trees and site when basal area is held constant gives a smaller increase in yield per unit increase in site. Consequently, a greater increase in site is required to produce a given increase in yield when basal area is the density control.

The relationship of yield and site portrayed in table 9 would not change under a thinning regime if basal area were maintained at the same level on all sites.

Table 9.--A comparison of yield relationships for natural slash pine at age 30 under two density controls

Site index (feet)	Per-acre density measure					
	400 trees			100 square feet of basal area		
	Basal area stocking	Wood yield	Yield increase per unit increase in site	Trees per acre	Wood yield	Yield increase per unit increase in site
	Square feet	Cubic feet	Percent	Number	Cubic feet	Percent
60	88	1,505	--	550	1,687	--
70	105	2,356	56.5	370	2,255	33.7
80	120	3,300	40.0	272	2,802	24.2
90	133	4,285	29.8	215	3,318	18.4
100	144	5,268	22.9	180	3,799	14.5

Practical Significance

The site increases required to raise production by given amounts suggest that the limits to site increases resulting from cultural treatments may be lower than previously thought. When we speak of doubling the yield of the average acre of slash pine without increasing the stocking level, it is evident that we are thinking in terms of increasing the site index by 30 to 55 feet, depending on the density variable employed and assuming the average site of natural slash pine to be 75. This is not to say that yields cannot be doubled through the use of innovative cultural treatments and genetic improvement. The important point is to recognize the challenge facing us and to plan our research efforts accordingly. Regardless of the outcome of such efforts, the seeming limitations on yield responses to cultural treatments emphasize the need to increase the stocking on understocked acres of slash pine.

LITERATURE CITED

Bennett, Frank A.
1970. Variable-density yield tables for managed stands of natural slash pine. USDA For. Serv. Res. Note SE-141, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

Buckman, Robert E.
1962. Growth and yield of red pine in Minnesota. USDA For. Serv. Tech. Bull. 1272, 50 p.

Collins, Arthur B., III
1967. Density and height growth in natural slash pine. U.S. For. Serv. Res. Pap. SE-27, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

Crowe, N. D.
1967. Growth, yield and economics of Pinus patula in the Natal Midlands. Univ. Stellenbach Ann. 42(2), Ser. A, 151 p.

Harms, William R., and Arthur B. Collins III
1965. Spacing and twelve-year growth of slash pine. J. For. 63:909-912.

Simmons, E. M., and G. L. Schnur
1937. Effect of stand density on mortality and growth of loblolly pine. J. Agric. Res. 54:47-58.

Spurr, Stephen H.
1952. Forest inventory. 476 p. The Ronald Press Co., New York.

Bennett, Frank A.
1975. Slash pine: some intriguing growth and yield relationships. USDA For. Serv. Res. Pap. SE-133, 12 p. Southeast. For. Exp. Stn., Asheville, N.C.

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USDA Forest Service Research Paper SE-134 June 1975

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by

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SUMMARY

Food choice, nutrient content, digestibility, and plant production in midsummer for white-tailed deer (Odocoileus virginianus) were evaluated on a clearcut and an adjacent selectively cut oak-pine stand in southwestern Virginia. In the clearcut area, tractable deer fed heavily on ripening fruits. In the selectively cut area, fruits were less abundant and the animals more often chose green leaves of forbs and deciduous hardwoods. Foods eaten most often by deer in the selectively cut area had a higher percentage of dry matter, crude protein, phosphorus, and ash, and had a higher gross energy content than plants in the clearcut area. Plants selected in the clearcut were more digestible (in vitro dry matter disappearance) and had a higher percentage of soluble carbohydrates. Total vegetation less than 1.2 m (5 feet) in height was three times greater per unit area on the clearcut than on the partial cut. Plant species selected most consistently as food by deer were 2.6 times more abundant in the clearcut. The initial advantage of clearcutting for increasing potential carrying capacity in summer may be negated, however, by the length of time between regeneration cuttings.

This Paper reports the results of a midsummer range analysis of adjacent clearcut and selectively cut areas in the Southern Appalachians. The data presented are important for two reasons. First, forest managers need to know how wildlife are influenced by the methods they use for harvesting timber stands. Second, the method of range analysis is complete, in that it determines the utilization and digestion of vegetation by deer as well as the amount and nutrient quality of the vegetation produced.

STUDY AREA

We selected areas on the Jefferson National Forest in southwestern Virginia where two types of cuttings of approximately the same age shared similar site conditions. Study areas were relatively small because site quality can change quickly over a short distance in the mountains and because selective cutting on the National Forest was discontinued in mid-1960 after clearcutting became the management policy.

The areas selected were in the oak-pine type. Approximately 4 hectares (10 acres) were chosen within a large clearcut where all vegetation over 5.1 cm (2 inches) d.b.h. had been cut 6 years before. An area approximately half this size was chosen in the adjacent stand, which had been selectively cut 5 years before to serve as a visual buffer between a secondary road and the clearcut. Approximately 7 m^2 basal area/hectare (30 ft^2 basal area/acre) of large pitch pine (Pinus rigida Mill.) and several oak species (Quercus spp.) were removed throughout the stand. The remaining stand had 21.35 m^2 basal area/hectare (93 ft^2 basal area/acre) in stems 7.6 cm (3 inches) d.b.h. and larger. Of the total basal area remaining, 44 percent was in trees 30.5 cm (12 inches) d.b.h. and larger, 23 percent in trees 22.9 to 27.9 cm (9 to 11 inches) d.b.h., 20 percent in trees 15.2 to 20.3 cm (6 to 8 inches) d.b.h., and 13 percent in stems 7.6 to 12.7 cm (3 to 5 inches) d.b.h.

Site index on both cut areas was 18.3 m (60 feet) at 50 years for pitch pine, and 16.2 m (53 feet) at 50 years for mixed oaks.

METHODS

Three tractable deer, trained to a leash while roaming in the woods, were used to determine food selection by deer. Details of this technique have been reported by Wallmo and Neff (1970); Healy (1971); and Whelan et al. (1971). These animals were 14 to 15 months old and had been captured as fawns and raised in captivity. Two were does and one was a castrated male. One of the does was ruminally fistulated.

Forage selectivity by lead deer was observed for 7 days in late July and early August on the clearcut area and for 3 days in early August on the partially cut area. A short timespan for sampling was chosen to allow comparison of treatment within the same phenological stage of plant growth. Sampling took longer in the clearcut because it was larger than the selective cutting and had a greater abundance and variety of plants. At approximately 0700 each day, the animals were transported 11 miles in a covered truck to the study area. A handler led the deer to one of three systematically selected portions of the densely vegetated clearcut area or to the unstratified, more penetrable, partial cut. The deer roamed for 45 minutes to 1 hour--longer periods resulted in less interest in feeding and more in traveling. It was sometimes necessary to encourage the deer to penetrate the clearcut or to restrain them to the sample area with the leash. Upon completion of field sampling the animals were returned to their pens and fed ad libitum a pelleted ration supplemented with alfalfa hay.

The animals were taken to the study area daily for a week to familiarize them with the area and the plants available. On all trips after the familiarization period, each observer dictated into a tape recorder the food items selected by each animal. Leaves, fruits, and larger flowers consumed by the animals were counted. Each 5.1-cm (2 inches) section, or fraction thereof, of herbaceous or woody stem or of small flowers clustered on a spike was considered as a unit. A 5.1-cm unit was selected because that amount approximated a single bite, but an animal often plucked and consumed a stem considerably longer than 5.1 cm in several bites.

Samples of vegetation were hand-plucked every other day during the sampling period and mixed to form a composite diet. Samples summarizing several days of plant selection were also collected. These diets were prepared by combining individual plant parts to form a mixture in which plant parts were represented according to their percentage of occurrence in the diets of the deer. Individual plants and the composite diets were analyzed for nutrient composition by proximate analysis and for digestibility by in vitro dry matter disappearance (IVDMD). Inocula from the ruminally fistulated lead doe were used in in vitro microdigestion trials. Processing of these samples was similar to the procedures reported by

Whelan et al. (1971). The procedure for IVDMD was a modification of the microdigestion technique reported by Pearson (1970). Samples were prepared for colorimetric determination of phosphorus by a wet-ashing procedure using nitric and perchloric acids. Percent of soluble carbohydrates was determined by hydrochloric acid extraction (Okajima and Smith 1964) and assayed using Dreywood's anthrone reagent (Morris 1948).

The standing crop of vegetative production less than 1.52 m (5 feet) in height was measured during mid-August. Sampling was stratified by area to insure adequate distribution. Plots were randomly located within each stratum. Each plot consisted of six 1 m^2 sampling units established 1 m apart following a compass bearing. Twelve plots were equally divided into three strata in the clearcut. The selective cut had four plots in one stratum and five in another. Vegetation weight was determined following a modification of the sampling technique used by Crawford (1971). Weights of current season growth of plant parts were estimated by species if they appeared to weigh less than 50 g. Parts thought to weigh over 50 g were clipped and weighed. After the weight of current growth on each plot was estimated, the estimated vegetation on one plot in six was randomly selected for clipping and weighing. Data were processed following Crawford's (1971) method except that ovendry weights of leaves, twigs, fruits, and flowers were determined by species.

RESULTS

Food Choice

Choice of foods by deer differed between clearcut and selectively cut areas (table 1). In the clearcut area, all animals fed heavily on ripening fruits, largely blueberry (Vaccinium spp.) and huckleberry (Gaylussacia spp.), which were abundant and well distributed. Fruits were less abundant in the selectively cut area, and the animals chose green leaves of forbs and deciduous hardwoods more often than fruits. Goldenrod (Solidago spp.), aster (Aster spp.), panic grass (Panicum spp.), low blueberry (V. vacillans Torr.), and huckleberry leaves were often eaten in the selectively cut area. Green leaves were also important food items in the clearcut, where the fistulated doe chose leaves more often than fruits. Goldenrod, violet (Viola spp.), low blueberry, blackgum (Nyssa sylvatica Marsh.), and blackberry (Rubus spp.) leaves were commonly eaten in the clearcut area.

The deer chose proportionately more woody and herbaceous stems in the selectively cut area than in the clearcut; the succulent stems of forbs were most often chosen. Low blueberry twigs were eaten in both areas while the animals were selecting fruit and leaves.

Consumption of flowers was limited in both areas. Flowers of aster were more often eaten than those of any other species.

Table 1.--Percent choice of food items selected by deer in a clearcut and partial cut area

Plant	Fistulated doe		Doe		Castrated buck	
	Clearcut	Selective cut	Clearcut	Selective cut	Clearcut	Selective cut
	Percent					
Fruit:						
Forbs	1	2	1	1	5	1
Deciduous hardwoods	41	16	57	21	51	4
Broadleaf evergreen	0	0	(1)	0	0	0
Subtotal	42	18	58	22	56	5
Leaves:						
Forbs (green)	33	42	10	28	18	38
Forbs (dry)	0	0	(1)	0	1	0
Deciduous hardwoods (green)	17	27	23	23	10	29
Deciduous hardwoods (dry)	0	0	1	(1)	1	0
Grasses and sedges	1	4	3	14	4	13
Ferns (fronds)	(1)	0	(1)	0	(1)	0
Subtotal	51	73	37	65	34	80
Stems:						
Forbs	2	5	1	5	3	10
Other (hardwoods, conifer, grasses and sedges)	2	2	1	5	3	3
Subtotal	4	7	2	10	6	13
Flowers:	2	2	2	1	4	1
Total[2]	99	100	99	98	100	99

[1] Trace.
[2] Because of rounding, column totals may not equal 100 percent.

Plants and plant parts that comprised approximately the top 75 percent of the units consumed during the study were considered key foods for habitat analysis. Table 2 shows the plant species and parts selected most often and the percentages that these items contributed to the total diets in clearcut and selectively cut areas. Daily variations in consumption were considerably less for these key plants than for the balance of foods consumed. For the clearcut area, nine species or genera represented 75 percent of the total diet over a 1-week period, and 57 other species made up the balance of the diet. In the selectively cut area, 13 species or genera represented 75 percent of the total diet for a 3-day period, and 39 other species completed the diet.

Table 2.--Percent of total food units selected by deer and production of summer understory vegetation in ovendry kilograms per hectare of key plant species

Species	Clearcut		Selective cut	
	Percent	Kg/ha	Percent	Kg/ha
Blueberry, deerberry and huckleberry fruit	41	28.7	10	6.2
Goldenrod leaves	5	9.8	11	3.7
Blueberry and huckleberry leaves	7	333.7	8	143.5
Panic grass stems and leaves	0	--	14	3.5
Violet leaves	9	2.8	4	3.2
Aster leaves and stems	2	2.0	9	4.3
Blackgum leaves	3	70.8	2	4.5
Goldenrod flowers and stems	0	--	4	.2
Blackberry fruit	3	(1)	0	--
Hickory leaves	0	--	3	12.2
Tick-trefoil leaves	0	--	3	4.5
Aster flowers	2	.5	0	--
Blackberry leaves	2	2.8	0	--
New Jersey tea leaves	0	--	2	9.3
Loosestrife leaves	0	--	2	3.2
New Jersey tea stems	0	--	1	3.7
Sassafras leaves	1	96.0	0	--
False Solomon's seal leaves	0	--	1	2.8
Little bluestem leaves	0	--	1	.5

[1] Trace.

Food Quality and Digestibility

Composite samples of key food plants in the selectively cut area had higher percentages of dry matter, crude protein, phosphorus, and ash and had higher gross energy than did samples from the clearcut area (table 3). Composite samples of plants selected in the clearcut, however, were more digestible and were higher in percentage of soluble carbohydrates.

Differences in dry matter content were small. Crude protein was 2.3 percentage points greater in the selectively cut area, but protein levels of both composite samples were above what is considered the maintenance level of 6 to 7 percent and below the optimum growth level of 13 to 16 percent (French et al. 1955). Ash was 3 percentage points higher in the selectively cut area, but, more importantly, phosphorus, often a deficient element in native forages (Halls 1970), was also considerably higher. Although gross energy of composite diets was higher in the selectively cut area than in the clearcut, IVDMD and soluble carbohydrates, indicators of readily available energy, were higher in the clearcut.

Table 3.--Nutrient analysis and *in vitro* dry matter disappearance of summer composite diet

Nutrient	Clearcut (7/26-7/30)	Partial cut (8/4-8/6)
	- - - - - - - Percent - - - - - - - -	
Crude protein	8.03	10.28
Ash	5.33	8.02
Phosphorus	0.11	0.16
Dry matter	21.22	23.61
In vitro dry matter disappearance (IVDMD)	49.96	43.73
Soluble carbohydrates	13.38	9.82
	- - - - - - - - Kcal/g - - - - - - - -	
Gross energy	4.38	5.14

Plant parts of several commonly eaten species were selected from each study area for analysis. Chemical composition varied widely by species and plant parts (table 4). The highest protein levels, 9 to 11 percent, of commonly eaten species were below the optimum for growth but above the maintenance level. Phosphorus levels were highest in violets, blackberry fruit, and leaves of blackgum. However, these levels were lower than the 0.25-percent minimum considered necessary for survival of bucks (Magruder et al. 1957). Blueberry, huckleberry, and blackberry fruits were high in soluble carbohydrates but moderate in gross energy values and IVDMD. Gross energy values were high for blueberry and huckleberry leaves and twigs, but IVDMD was lower than that for other plants. Blueberry and huckleberry leaves from the clearcut had the lowest IVDMD, 19 percent, of any sample. The IVDMD of these leaves in the selectively cut area was 31 percent, also a comparatively low value. Volatile oils in these ericaceous leaves might influence their IVDMD and also that of composite samples. The low IVDMD of these common plant parts may explain why such apparently digestible species as goldenrod, violet, and aster, with 60 to 75 percent IVDMD individually, were considerably less digestible in a composite sample that contained a substantial portion of ericaceous leaves. These differences also emphasize the importance of using composite samples to more truly represent rumen content when conducting microdigestion trials for range analysis.

Production Of Understory Vegetation

Total weight of understory vegetation produced during summer was over three times as great on the clearcut area as on the selectively cut area (table 5). Regenerating pitch and Virginia pine (*Pinus virginiana* Mill.), sprouts of white oak (*Quercus alba* L.), scarlet oak (*Q. coccinea* Muenchh.), and bear oak (*Q ilicifolia* Wangenh.), and dense low growth of laurel (*Kalmia latifolia* L.), blueberries, and wintergreen (*Gaultheria procumbens* L.) comprised over one-half the weight of vegetation in the

clearcut. Greenbrier (Smilax spp.), bracken fern (Pteridium aquilinum (L.) Kuhn), sassafras (Sassafras albidum (Nutt.) Nees.), and trailing arbutus (Epigaea repens L.) were well distributed throughout the clearcut area. Wintergreen, blueberries, and flowering dogwood (Cornus florida L.) made up almost one-half of the vegetative weight in the selectively cut area, while sassafras, red maple (Acer rubrum L.), white oak, and greenbrier occurred throughout.

Table 4.--Nutrient analysis and in vitro dry matter disappearance of individual plants and parts

Species and plant part	Crude protein		Phosphorus		Dry matter		IVDMD[2]		Soluble carbodydrates		Gross energy	
	Clear-cut	Sel.[1] cut	Clear-cut	Sel. cut	Clear-cut	Sel. cut	Clear-cut	Sel. cut	Clear-cut	Sel. cut	Clear-cut	Sel. cut
	Percent										Kcal/g	
Low blueberry and huckleberry (leaves)	7.94	7.38	0.06	0.05	48	39	19	31	11.69	10.71	5.02	4.49
Low blueberry and huckleberry (fruit)	4.00	4.13	.04	.07	21	21	58	56	25.09	24.49	4.53	4.34
Low blueberry and huckleberry (twigs)	4.13	3.88	.06	.06	59	44	21	22	--	7.12	5.01	5.12
Deerberry (fruit)	3.88	3.57	.07	.08	16	18	52	54	10.87	11.49	4.68	4.59
Goldenrod (leaves)	9.82	9.31	.06	.08	32	26	61	68	10.36	8.67	4.69	4.42
Goldenrod (flowers)	--	9.26	--	.06	--	28	--	52	--	8.62	--	4.52
Violet (plants)	10.63	--	.12	--	21	--	75	--	12.48	--	4.31	--
Blackberry (fruit)	6.32	--	.11	--	17	--	53	--	16.46	--	4.57	--
Blackgum (leaves)	10.26	--	.10	--	37	--	43	--	8.52	--	4.78	--
Aster (leaves)	--	10.32	--	.07	--	26	--	69	--	9.82	--	4.20
Panic grass (plant)	--	6.91	--	.07	--	32	--	55	--	6.03	--	4.38

[1] Selectively cut.
[2] In vitro dry matter disappearance.

Table 5.--Ovendry production of summer understory vegetation and 95-percent confidence limit on clearcut and selectively cut areas

Vegetation category	Clearcut	Partial cut	Ratio of means
	Kg/ha		
Total production	2,863 ± 266	846 ± 123	3.4
Total foods	2,573	518	5.0
Key foods	547 ± 145	205 ± 60	2.6

The key species most commonly eaten by deer were approximately 2.6 times as abundant in the clearcut as in the selectively cut area (table 5). Well over half of the standing crop, 334 kg/hectare (298 lb/acre), in the clearcut was composed of blueberry and huckleberry leaves (table 2), while sassafras and blackgum leaves yielded 96 (86) and 71 kg/hectare (63 lb/acre), respectively. Fruits of blueberry and huckleberry amounted to 29 (26) and 6 kg/hectare (5 lb/acre) in the clearcut and selectively cut areas, respectively. Blueberry and huckleberry leaves contributed almost 70 percent of the total weight in the selectively cut area. Hickory (Carya spp.), New Jersey tea (Ceanothus americanus L.), and leaves of several other species including false Solomon's seal (Smilacina racemosa (L.) Desf.), bluestem (Andropogon scoparius Michx.), tick-trefoil (Desmodium spp.), and loosestrife (Lythrum spp.) among others contributed small amounts (table 2).

If the summer production of all plants eaten by deer is considered, the clearcut has almost five times more forage than the selectively cut area (table 5). Habitat analysis, however, should probably be based on only commonly eaten key species (the top 75 percent). The balance of the diet included many plants that were taken incidentally while feeding. For instance, black oak (Q. velutina Lam.), Virginia pine, and mountain laurel, although relatively abundant, were taken only in small amounts by one or two animals. Hence, the advantage of the clearcut for production of deer food per unit of area is only 2.6 times that of the selectively cut area.

DISCUSSION

We compared range potential for deer by evaluating the weight of key deer foods available, and the gross energy content and apparent digestibility of these foods. Two necessary assumptions were that IVDMD of the foods is closely related to in vivo digestibility, and that dry matter digestibility is closely related to apparent digestible energy. These assumptions have been accepted for work with domestic animals (Moir 1961; Van Dyne 1968).

Key foods in the clearcut area contained 1.20 million kcal/hectare of apparent digestible energy compared with 0.45 million in the partial cut. Enough food energy is available in the clearcut area to support 2.6 times more deer of similar size per hectare than could be supported in the selectively cut area during the summer in which we sampled. As the vegetation in the clearcut grows taller in subsequent years, it will no longer be in reach of deer, and its dense canopy will limit the amount of understory growth. The vegetation in the selective cut will also grow beyond reach, but the higher canopy will not limit understory growth as much as the denser sapling and small pole canopy in the regenerating clearcut. Hence, we expect the advantage ratio of 2.6 (table 5) for the clearcut to decrease.

It will be many years before the clearcut matures and is ready for the next regeneration cut. The partially cut area can be commercially cut again relatively soon, since only about 20 percent of the volume was removed. With a 100-year rotation (approximately correct for this site) the stand could be cut again at approximately the same intensity in 20 years. In contrast, the clearcut would not be cut for regeneration before 100 years. The apparent advantage of clearcutting for wildlife must be spread over the life of the stand. Deer forage in the selectively cut stand will be rejuvenated by regeneration cuts four times during the next 80 years, while the clearcut stand is dependent on thinnings for stand disturbance. Thinning cuts may or may not rejuvenate deer forage. Depending on the interaction of site, cutting intensity, stand age, and source of propagules, the vegetative response in stands containing oaks may be from species of little or no food value or of substantial food value (Crawford 1971).

The initial advantage of clearcutting for increasing summer range potential was small when considering the period of time that elapses between regeneration cuttings. As shown in table 5, the advantage of increasing important forage plants by clearcutting (2.6) was much smaller than that for total vegetation yields (3.4) or yields of total deer foods (5.0). Crawford and Harrison (1971) studied dormant season wildlife food plants on clearcut and selectively cut sites. The advantage ratio for wildlife in clearcuts vs. selective cuts was 20.0 but decreased to 4.0 when yields were considered over the entire regeneration cycle. Using data from the present study and following the same line of reasoning as posed by Crawford and Harrison, in a 10,000-hectare (24,710 acres) stand that contains trees ready for harvest at 100 years, 100 hectares (247 acres) could be clearcut under even-aged management and 500 hectares (1,236 acres) could be selectively cut for regeneration with uneven-aged management during each of the 100 years. Applying the energy and digestibility data from table 3 to the production of key summer foods shown in table 5, we find that the 100-hectare clearcut would yield 120 million kcal of digestible energy compared with 230 million kcal for the 500 hectares selectively cut area each year, almost a twofold advantage for selective cutting. The advantage accrues to selective cutting because more area is cut each year. This theoretical comparison assumes that other factors such as mast production are equal for both cutting systems. We do not know if a bias is introduced by making this assumption.

Responses of deer habitat potential to precommercial and commercial thinnings in this forest type are unknown, but at this time any type of cutting other than regeneration cutting is a questionable economic practice on relatively unproductive hardwood and mixed pine-hardwood sites over much of the Appalachians. If even-aged management is applied, therefore, positive measures should be considered to improve summer deer habitat during the long intervals between clearcuts. The improvement in deer habitat caused by thinning, for example, may help offset the cost of such a practice. With the repeated selective cutting of uneven-aged management, additional measures to improve summer deer habitat seem less essential.

This study indicates that selective cutting has greater potential for improving summer deer range than does clearcutting when only regeneration cuts are possible. The amount of acreage sustaining regeneration cutting each year was more important for increasing summer deer range potential on the site studied than were differences in vegetation yield or nutrient content and digestibility of the forage plants for deer.

It should be emphasized, however, that we have presented only one part of the complex interaction of timber management and forest wildlife. We studied one site in depth during one season and cannot reliably extrapolate these findings to other seasons or substantially different sites. Our findings represent an in-depth analysis and go beyond the usual practice of sampling vegetation and speculating upon utilization and value of the plants to the animals. This work provides a basis for comparing deer range values with those of other sites and seasons and offers an interesting hypothesis for further testing.

LITERATURE CITED

Crawford, H. S., Jr.
1971. Wildlife habitat changes after intermediate cutting for even-aged oak management. J. Wildl. Manage. 35:275-286.

Crawford, H. S., Jr., and W. M. Harrison
1971. Wildlife food on three Ozark hardwood sites after regeneration cutting. J. Wildl. Manage. 35:533-537.

French, C. E., L. C. McEwen, N. D. Magruder, and others
1955. Nutritional requirements of white-tailed deer for growth and antler development. Pa. Agric. Exp. Stn. Bull. 600, 50 p.

Halls, L. K.
1970. Nutrient requirements of livestock and game, p. 10-18. In Range and wildlife habitat evaluation--a research symposium. 1968. USDA Misc. Publ. 1147.

Healy, W. M.
1971. Forage preferences of tame deer in a northwest Pennsylvania clear-cutting. J. Wildl. Manage. 35:717-723.

Magruder, N. D., C. E. French, L. C. McEwen, and R. W. Swift
1957. Nutritional requirements of white-tailed deer for growth and antler development. II. Experimental results of the third year. Pa. Agric. Exp. Stn. Bull. 628, 21 p.

Moir, R. J.
1961. A note on the relationship between digestible dry matter and the digestible energy content of ruminant diets. Aust. J. Exp. Agric. Anim. Husb. 1:24-26.

Morris, D. L.
1948. Quantitative determination of carbohydrates with Dreywood's anthrone reagent. Science 107(2775):254-255.

Okajima, H., and D. Smith
1964. Available carbohydrate fractions in the stem bases and seeds of timothy, smooth bromegrass, and several other northern grasses. Crop Sci. 4(3):317-320.

Pearson, H. A.
1970. Digestibility trials: in vitro techniques, p. 85-92. In Range and wildlife habitat evaluation--a research symposium. 1968. USDA Misc. Publ. 1147.

Van Dyne, G. M.
1968. Measuring quantity and quality of the diet of large herbivores. In A practical guide to the study of large herbivores, p. 54-94. F. B. Golley and H. K. Buechner, eds. IBP Handb. 7.

Wallmo, O. C., and D. J. Neff
1970. Direct observations of tamed deer to measure their consumption of natural forage, p. 105-110. In Range and wildlife habitat evaluation--a research symposium. 1968. USDA Misc. Publ. 1147.

Whelan, J. B., R. F. Harlow, and H. S. Crawford
1971. Selectivity, quality, and in vitro digestibility of deer foods: a tentative model. 28th Northeast. Fish & Wildl. Conf. Trans., Northeast. Sect. Wildl. Soc., p. 67-81.

Crawford, Hewlette S., James B. Whelan, Richard F. Harlow, and John E. Skeen

1975. Deer range potential in selective and clearcut oak-pine stands in southwestern Virginia. USDA For. Serv. Res. Pap. SE-134, 12 p. Southeast. For. Exp. Stn., Asheville, N. C.

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SDA Forest Service Research Paper SE-135 · June 1975

Slash Pine Productivity and Site Preparation on Florida Sandhill Sites

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Slash Pine Productivity and Site Preparation on Florida Sandhill Sites

by

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INTRODUCTION

In the Florida sandhills the productivity of slash pine varies greatly. Most sites are poor, but some stands grow well. Volumes as high as 3,585 and as low as 401 cubic feet per acre have been measured in 24-year old stands. On poor sites slash pine may grow well at first if competing scrub vegetation has been eliminated. After a few years, however, growth declines, and with increasing age the stands begin to deteriorate.

Probably the basic cause of this variability is the soil itself. Deceptively uniform at the surface--sand with usually rapid to excessive drainage--it can differ markedly with depth. Below 4 feet there are often present one or more layers of soil containing sufficient fine-textured material to impede internal drainage. A number of site index studies of slash pine have indicated that certain site factors, such as soil depth, are particularly important (Barnes and Ralston 1955; Kreis, Bennett, and Patterson 1956; McGee 1961; Row 1960). Only in Row's study, however, was the work conducted exclusively in the sandhills.

This Paper discusses ways to evaluate the suitability of sandhill sites for slash pine and the effects of site preparation on site quality. Primary data are those from a soil-site study originated in northwest Florida by R. H. Brendemuehl, who also contributed a large part of the field work. Supplementary data show the effect of various site preparation treatments on productivity of slash pine plantings in one such area within that region.

METHODS

Ninety-one slash pine plantations growing on a variety of sandhill soils from Tallahassee to Pensacola were examined. Originally the selections included only unburned, unthinned, and unpruned plantations, but standards had to be relaxed because so few stands met these criteria. Table 1 shows the distribution of plots by site index at age 25, age, and stand density.

Plots were located in plantations established on well- to excessively drained soils having a sandy surface soil at least 30 inches thick. Each plot was limited in area to a nine- by nine-tree rectangle and varied in size with the original spacing of trees. Soil profile descriptions were obtained from four 3-inch bucket auger samples taken approximately equal distances from the plot center and the corners. Plots were discarded if the soil profile differed markedly from sample point to sample point within a given plot.

Table 1.--Sample plot distribution by site index, age class, and stand density

Site index at 25 years	Age class (years)										
	8	10	12	14	16	18	20	22	24	26	Total
	Number of plots										
30			1								1
40		2	2								4
50			1	2				1			4
60	1	1	6				6	1		2	17
70	3	8	11	7	1	4	8	7	2		51
80	2	3	2			1	2	1		1	12
90	1	1									2
Total	7	15	23	9	1	5	16	10	2	3	91

Site index at 25 years	Stand density (trees per acre) class							
	200	500	800	1100	1400	1700	2000	Total
	Number of plots							
30		1						1
40		1	1	2				4
50	1	1		1			1	4
60	7	5	3	1	1			17
70	19	17	7	7	1			51
80	6	2	4					12
90	1		1					2
Total	34	27	16	11	2		1	91

The aspect, elevation, slope, and topographic position of plots were noted. A record also was made of the apparent cultural history (grazing and site preparation); type of natural vegetation; spacing of the trees in the stand; presence, size, and abundance of scrub oak which characterize sandhill soils and hinder the establishment and growth of pines; and occurrence of the stem canker, Cronartium fusiforme Hedg. and Hunt. Tree measurement data were collected from five dominant or codominant trees, one near each auger hole and one at the center of the plot.

Soil samples composited from two sample points within each plot were analyzed. Soil color was determined according to the Munsell system, organic matter content of the A horizon by loss of weight on ignition, sand separates by dry sieving, moisture equivalent of the C and fine-textured horizons by centrifugation, and particle-size by the hydrometer method.

A curve of height over age for trees in the 20- to 25-year age class was constructed by stem analysis and this was used to derive a family of site index curves (fig. 1). Site indexes were determined for the plots and these were compared with the variation of recorded site variables.

Quantifiable factors were screened graphically and then tested in a regression program for association with the productivity of the trees of each plot. Twenty-three independent variables were screened but only ten were used in the final regression. These are shown, together with the

range in value of each, in table 2. A number of factors found significant elsewhere in the Southeast and tested here were thickness of the A horizon, organic matter content of the A horizon, and silt plus clay content of the fine-textured material.

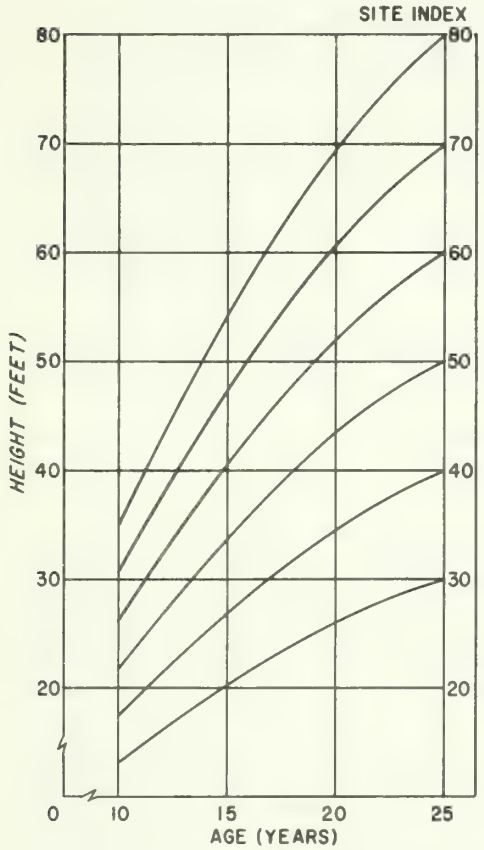

Figure 1.--Site index curves for slash pine in the Florida sandhills. These curves were developed from stem analysis data by anamorphosis, with Curtis's (1964) correction for distortion.

Table 2.--Variables used in the regressions and their ranges

Variable	Range
1. Depth to fine-textured material	47 to 191 inches
2. Elevation of the plot above mean sea level	80 to 320 feet
3. Elevation above the scarp of the coastal plain terrace on which the plot was located	5 to 120 feet
4. Plantation density (trees per acre)	94 to 2,073 trees
5. Thickness of the A horizon	4.9 to 9.0 inches
6. Medium sand content of the C horizon	23 to 62 percent
7. Plot distance west of Tallahassee	8 to 159 miles
8. Silt + clay content of the fine-textured material	3 to 37 percent
9. Organic matter content of the A horizon	0.81 to 2.29 percent
10. Moisture equivalent of the C horizon	1.57 to 4.54 percent

Analyses employing the BMD02R program (Dixon 1964) were run with stepwise and forward-selection procedures to determine the best regression. The dependent variable, site index of slash pine at age 25, ranged from 44.4 to 81.1 feet.

Not all plots sampled in the field were included in the final regression analysis: 12 were discarded because of aberrations or because they lacked the full complement of data, and only plots bearing trees at least 11 years old were used. Younger stands were found to introduce much variability because of their wide regional distribution. The final regression included data from 54 plots. (This total is not obtainable from table 1 because some of the aberrant plots were also too young, and age class 12 of the table includes some plots with 11-year-old trees.)

Further evaluation of the relationships between site characteristics and growth was made with data from a site preparation study installed on the Chipola Experimental Forest in northwest Florida. In that study the effectiveness of several methods of preparing land for planting pine was tested. Most methods used were mechanical, but prescribed fire was used preceding most of the mechanical treatments and as one of the methods. A Mathis fire plow, a heavy-duty Rome disk harrow, and 4½-, 8-, and 11-ton duplex brush cutters (choppers) were used. Survival and height of slash pine through plantation age 10 were used to evaluate the treatments; depth to the fine-textured horizon was used as the concomitant variable in an analysis of covariance.

RESULTS AND DISCUSSION

The most significant contributions to the regression equation were depth to the layer of fine-textured material (DFT), number of trees per acre (TA), and the percent medium sand (particles 0.5 to 0.25 mm) in the C horizon (MSC). The best regression, based on 54 plots, was

$$SI_{25} = 84.0 - 0.07(DFT) - 0.007(TA) - 0.19(MSC)$$

with $R^2 = 0.40$ and standard error of estimate = 6.30.

Many variables, after being tested graphically, were discarded because they lacked promise. These included the position of plots on the slope and various expressions of slope itself, the moisture equivalents of the different soil horizons, and most of the sand separates. None of the variables commonly considered effective, particularly the organic matter content and thickness of the A horizon, contributed significantly to the regression. Nor did logarithmic transformations effect any improvement. No relation of site index to the incidence of Cronartium fusiforme could be found, although many plots contained infected trees.

The association of pine productivity with decrease in depth to the layer of fine-textured material parallels Barnes and Ralston's findings in Florida (1955) and bears out observations in many slash pine stands on sandhill sites. It seems likely that the primary effect of this factor is on available water. The fine-textured layer retards percolation and in itself retains moisture much longer than sand. Thus, it apparently acts in the manner of a water table. The higher the layer in the profile, the more moisture is available to the roots above. It appears (fig. 2) that the effect of the layer on raising the level of water available to slash pine is not felt unless the layer is above a depth of 12 feet; therefore, the better slash pine sites are those where the layer of fine-textured material is closer than that to the surface.

The significance of the proportion of medium sand in the C horizon is difficult to explain. It could be related to the availability of soil moisture, though it is puzzling why the medium rather than a fine sand should show this relationship. Zahner et al. (1964) found that very fine

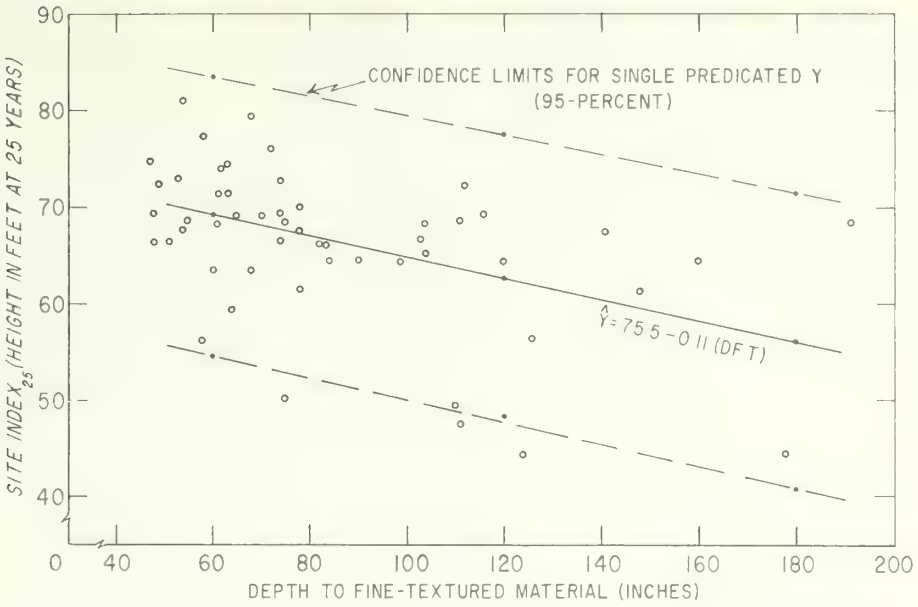

Figure 2.--Regression of site index on depth to fine-textured material.

sand yielded the most available water to jack pine stands: 23 percent, compared to an average of 3 percent from coarse, medium, or fine sand. The comparative difficulty of determining the proportion of medium sand in the C horizon (a laboratory procedure) limits the usefulness of this equation in the field.

Stand density showed significance in the most efficient equation, but there was a wide range within which this variable had little influence. Its statistical importance was due mainly to one plot with an extremely high density--2,073 trees per acre. The average number of trees per acre for the study was 471, a more appropriate density for a droughty impoverished soil.

Field estimates were improved by using a one-variable equation employing depth to fine-textured material and simply measuring that depth. The equation,

$$SI_{25} = 75.5 - 0.11(\text{DFT in inches})$$

describes this relationship (fig. 2). Site index for slash pine decreases approximately one foot for every 9 inches of depth to this layer.

Considering the time and cost of field estimates, this is probably the equation to use. It accounts for 20 percent of the variability and has a standard error of estimate of 7.12. Confidence limits for the regression (for a single predicted Y) at the mean depth to fine-textured material are $\pm$ 14.42.

There are other indications that depth to fine-textured soil is an important factor. Findings in site preparation studies confirm that it affects height growth. Gross treatment differences between plots in one such study were significant, but soils varied from plot to plot. An analysis of covariance that introduced soil depth as a concomitant variable removed a significant amount of variation and improved the precision of analysis of both tree height and diameter. Resulting adjusted height

values (table 3) match quite closely those obtained by applying the regression of site index on depth to fine-textured material embodied in the predictive equation

$$SI_{25} = 75.5 - 0.11(DFT)$$

Table 3.--Height by treatment in a comparative site preparation test, as adjusted by covariance analysis and by a regression formula

Site treatment	Average tree height	
	Adjusted by the covariate	Adjusted by the site index formula
	- - - - - - Feet - - - - - -	
None	6.4	6.2
Fire	7.4	7.3
Mathis fire plow	9.5	9.6
Fire + heavy chopper	12.9	13.0
Fire + disk harrow + disk harrow	14.6	14.8
Fire + heavy chopper + disk harrow	17.1	17.4
Fire + rootrake + disk harrow	17.3	17.4
Heavy chopper + heavy chopper	17.5	17.4
Fire + heavy chopper + light chopper	18.2	18.3
Fire + heavy chopper + medium chopper	17.7	17.3

After adjustment for differences in site, the comparative differences between various site preparation treatments were still the same, or approximately so: pines were largest on the more intensively prepared sites, burning by itself was of little benefit, and the heaviest equipment did the best job, though lighter equipment could have been used more economically and with equally good effect for the second half of the treatment (Burns 1973).

Site preparation itself affects both survival and growth--that is why such treatments are used--and different site treatments give different degrees of benefit. By lessening or virtually eliminating established competition, site preparation improves survival and confers an early growth advantage on the planted trees. Rapid growth does not persist through the life of the stand, however, unless the site has the capability of sustaining it. We noted a decline in growth at about age nine on excessively drained sites.

The influence of depth to fine texture on site quality is revealed early in the life of the trees. Periodic measurements of tree height (fig. 3) show that on plots where the layer of fine-textured material is close to the surface, superior growth is apparent in plot averages at a very early age. Other than the untreated controls, treatments included in the figure are only those involving a double operation; i.e., at least two successive treatments with an interval of several weeks between. Height growth tends to increase as depth to fine-textured material decreases. Where superior growth is displayed by one replication, it is evident as early as the second year. This is apparent both on the plots receiving intensive treatment and control plots. From a detailed analysis of slash and other pines, Wakeley (1971) concluded that superior trees could not be identified at ages earlier than 15, but he was correlating growth in individual trees. Here we are concerned with averages associated with a group, all trees of which were treated alike.

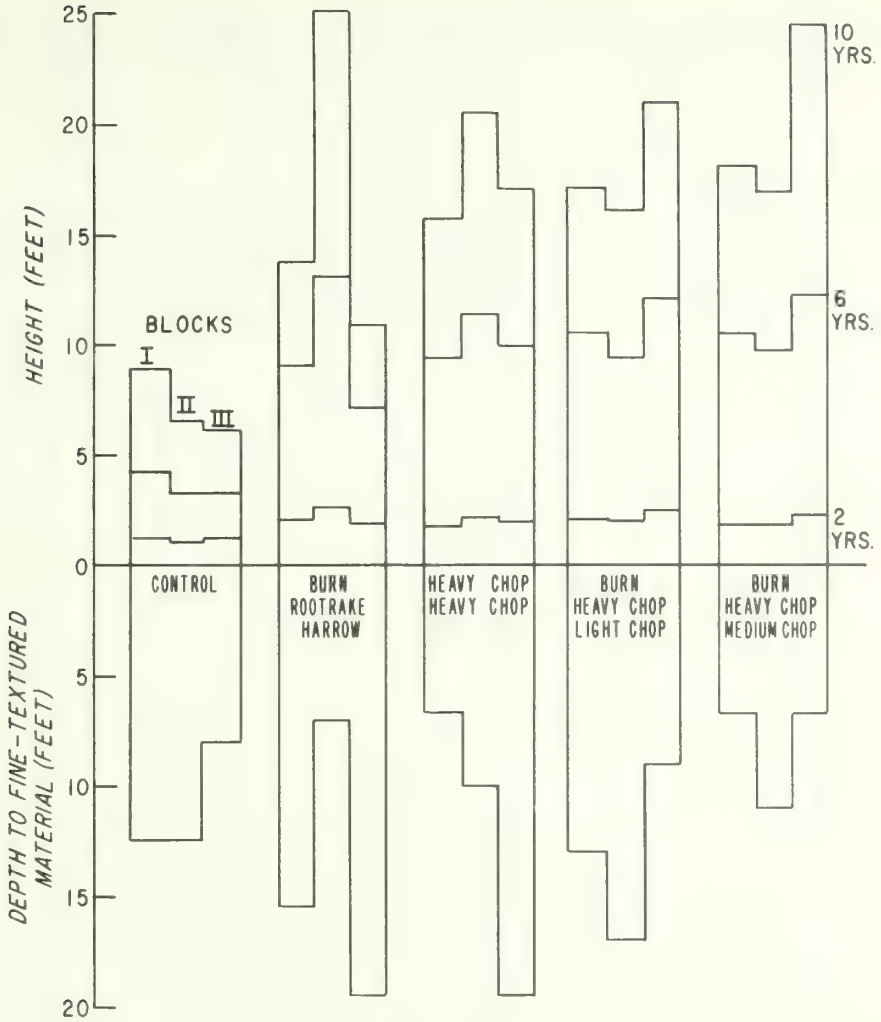

Figure 3.--Relationships between average tree height at plantation ages 2, 6, and 10 years and soil depth in selected treatments. Differences in average tree height are revealed at an early age.

SIGNIFICANCE FOR SITE INDEX WORK

Elimination of competition cannot improve poor soil, but it can improve growth in the early life of trees. The influence of soil should prevail over site preparation (Ralston and McGee 1962), but site preparation does make more of the capacity of the site available to the newly planted trees rather than to competing vegetation. Planting survival and early growth are improved, and this early advantage persists for a time. As a consequence, site determinations that are reflected in tree growth are raised in value to more closely express the productive capabilities of the site.

Site index results should be evaluated in the light of land treatment. This means that comparisons of treated and untreated lands should be made with care. Where there is a pattern of farming and subsequent abandonment to woodland growth, any determination of site index probably will be confused by the differences in treatment to which the sites had

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USDA Forest Service Research Paper SE-136 July 1975

Deer Browse Resources of the Chattahoochee National Forest

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Deer Browse Resources of the Chattahoochee National Forest

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The quantity of various forages available to deer on the Chattahoochee National Forest in Georgia was determined during the fall and winter of 1967. This Paper reports the quantity, frequency, density, and utilization of browse plants by forest type. These data are needed to ascertain which forest types most need management. Since this survey was conducted on permanent Continuous Forest Inventory (CFI) plots, it will also be possible, following future surveys, to determine browse production and utilization trends within a type.

The 681,000-acre Chattahoochee National Forest is located in 17 counties in the Appalachians of northern Georgia. The mountainous topography (elevations vary from 1,200 to nearly 5,000 feet) results in a wide variety of climatic and ecological conditions, and the variety of flowering plants occurring there is one of the greatest in the Western Hemisphere.

METHODS

Fourteen forest types were sampled in the survey on a total of 496 CFI plots within the Chattahoochee National Forest (fig. 1). These were the same plots used in the original survey of this type reported by Ripley and McClure (1963). Changes in sampling procedures at each CFI plot from the first survey include:

1. Selection of four cylindrical milacre subplots, each 4.5 feet high, instead of 10 subplots.

2. Conversion of twig numbers and lengths on the milacre subplots to weight (air-dry pounds per acre) rather than estimation of browse weights from photographs. At the end of the growing season (September) new growth of twigs from 20 plants per species were clipped, measured for length, and weighed to determine factors for converting number of twigs and twig length to pounds of browse. The number of growing points or total twig lengths was multiplied by a weight conversion factor to arrive at weight in grams for each species in each quadrat. Evergreen species were assigned the same summer and winter weights. Yields from four plots per location were then averaged and viewed as a single observation.

Figure 1.--Area surveyed in northern Georgia.

Data collected on the four milacre subplots at each location included:

1. Number of plants for each woody species rooted on the subplot.

2. The total number of growing points (lateral and terminal) and the average length of current season twig growth up to 4.5 feet high for each species.

3. Presence or absence of utilization on current season growth for each species.

4. Percent occurrence of herbaceous vegetation.

Appendix table 8 shows the browse weight conversion factors as well as the scientific names of all plant species encountered on the plots. Field crews were instructed on plant identification and sampling procedures.

Each woody plant species was placed in one of the following preference classes:

Choice: Plants consistently utilized throughout the year.

Other: Plant utilization inconsistent or unknown.

The assignment of deer browse plants to these two preference classes was based on analysis of rumen samples of white-tailed deer and on deer browse studies in the Southern Appalachians as determined by Harlow and Downing (1970); Cushwa et al. (1970); and Harlow and Hooper (1971).

Percent utilization, percent occurrence, and browse weight (summer and winter) were analyzed separately in each major forest type.

Table 1 lists the 14 major forest types identified on the Chattahoochee Forest, the number of milacre plots taken, and the number needed in each type to detect a 50-percent change in plant weights per milacre plot 95 percent of the time. Sixty percent of the 1,984 milacre subplots taken were in the oak-pine and oak-hickory forest types. Another 12 percent were in the shortleaf pine type, and the remaining 28 percent were distributed among 11 other types. Nine of the 14 types were sampled sufficiently to achieve the designated limits of accuracy. These nine types constituted 98 percent of the total acreage in the Chattahoochee National Forest.

Table 1.--List of forest types showing number of milacre plots taken and number of plots required to detect a 50-percent change in plant weights and per milacre plot at the 95-percent level

Forest type	Acres in type	Milacre subplots taken	Total milacre subplots required
White pine	14,301	56	18
White pine-hemlock	5,788	16	19
Hemlock	2,724	8	43
Loblolly pine	9,670	28	26
Shortleaf pine	81,720	232	64
Virginia pine	30,236	88	23
Pitch pine	6,810	20	18
Table-Mountain pine	1,362	4	19
Oak-pine	211,111	608	58
Oak-hickory	204,572	596	56
Chestnut oak	64,695	188	52
Yellow-poplar-white oak-northern red oak	42,563	124	10
Southern scrub oak	1,362	4	33
Sweetgum-yellow-poplar	4,086	12	44
Total	681,000	1,984	483

RESULTS AND DISCUSSION

Browse Yields

The loblolly pine, sweetgum-yellow-poplar, oak-hickory, and oak-pine forest types contained the greatest quantity of "choice" winter browse for deer, while hemlock, pitch pine, and white pine-hemlock types had the least (table 2). Forage yields varied widely among plots in the white pine-hemlock, hemlock, loblolly pine, pitch pine, Table-Mountain pine, southern scrub oak, and sweetgum-yellow-poplar types, and relatively few plots were located in these types (table 2).

Table 2.--Air-dry pounds per acre of winter deer browse, percent woody plants browsed, and number of plant species present by forest type on the Chattahoochee National Forest. Forest types are listed in order of importance as producers of choice deer food

Forest type	Browse class	Plant species occurring on plots	Milacre subplots with plants browsed	Winter browse in class	Total winter browse with 95 percent confidence limits
		Number	Percent	Lbs/acre	Lbs/acre
Loblolly pine	Choice	11	8.3	223[1]	227 ± 111
	Other	16	2.2	4	
Sweetgum-yellow-poplar	Choice	10	6.6	38[1]	74 ± 72
	Other	12	3.1	36[2]	
Oak-hickory	Choice	24	9.2	22	63 ± 14
	Other	45	4.6	41[3]	
Oak-pine	Choice	23	9.7	19	147 ± 25
	Other	43	4.2	128[3]	
White pine	Choice	15	6.4	15	116 ± 34
	Other	18	5.7	101[3]	
Yellow-poplar-white-oak-northern red oak	Choice	18	13.2	15	37 ± 7
	Other	29	4.9	22	
Virginia pine	Choice	15	14.8	14	119 ± 31
	Other	16	10.4	105[3]	
Hemlock	Choice	5	12.5	14	36 ± 42
	Other	6	0	22[4]	
Table-Mountain pine	Choice	4	25.0	13	33 ± 37
	Other	6	0	20[5]	
Shortleaf pine	Choice	20	6.9	12	80 ± 21
	Other	38	5.3	68[3]	
Chestnut oak	Choice	17	9.0	11	169 ± 42
	Other	24	5.2	158[3]	
Southern scrub oak	Choice	5	0	9	195 ± 279
	Other	6	7.1	186[3]	
Pitch pine	Choice	6	3.3	7	343 ± 165
	Other	9	5.0	336[3]	
White pine-hemlock	Choice	6	8.3	2	192 ± 120
	Other	10	10.8	190[2]	

[1] Predominantly honeysuckle.
[2] Predominantly rhododendron.
[3] Predominantly mountain-laurel and/or blueberry.
[4] Predominantly hemlock.
[5] Predominantly white pine.

Only the loblolly pine forest type contained more than 40 pounds per acre of "choice" woody browse. Japanese honeysuckle accounted for 72 percent of the forage in this type. Based on total weight on the forest as a whole, mountain-laurel ranked highest, contributing 41 percent of all woody and leafy browse available (table 3); blueberry was next, followed by rhododendron, honeysuckle, greenbrier, and blackberry. These six plants produced 86 percent of the total weight of all browse available to deer. Honeysuckle, greenbrier, and blackberry are "choice" species and contributed almost 20 percent of the total browse supply. Twenty-three "choice" winter browse species provided to 25.7 percent of the total pounds per acre of available winter food, a surprisingly high figure. The seven major "other" plant species accounted for 66.9 percent of the total winter browse. An additional 51 woody plants contributed only 7.4 percent of the weight.

Table 3.--Density rating and relative quantities of the major browse plants on the Chattahoochee National Forest

Species	Milacre subplots plant occurred on[1]		Density index[2]	Forest types found on	Proportion of total pounds per acre[3]
	Number	Percent	Number	Number	Percent
Choice					
Honeysuckle	20	1.01	1,334.00	6	10.75
Brook euonymus	35	1.76	141.16	7	.09
Greenbrier	697	35.13	23.74	14	5.71
Allegany oilnut	32	1.61	19.60	5	.18
Azalea	176	8.87	32.38	11	1.94
Blackberries	108	5.44	31.27	9	3.17
Ashes	25	1.26	22.00	7	.03
Maples	561	28.27	18.50	12	.81
Viburnum	32	1.61	16.78	6	.03
Sweetshrub	72	3.63	15.50	7	.10
Grapes	53	2.67	15.11	7	.33
Dogwoods	360	18.14	12.72	11	.81
Black locust	51	2.57	12.55	8	.14
Sassafras	185	9.32	12.34	10	.21
Blackgum	386	19.45	12.12	13	.56
Sourwood	153	7.71	10.82	10	.56
Witchhazel	43	2.16	8.44	8	.02
Yellow-poplar	114	5.74	7.65	8	.09
Strawberry	22	1.11	6.50	5	.01
St. John's-wort	14	.71	43.70	4	.04
Hydrangea (vine)	8	.40	28.35	4	.12
Chinkapin	3	.15	4.00	3	.01
Cinnamon clethra	2	.10	4.00	1	--
Other					
Blueberries	882	44.45	296.00	11	13.31
Rhododendron	68	3.43	58.17	9	11.65
Mountain-laurel	398	20.06	31.94	10	41.24
Chestnut oak	371	18.70	13.20	9	.63
Scarlet oak	169	8.52	11.21	9	.04
New Jersey tea	40	2.02	54.30	7	.01
Hickory	396	19.96	9.15	12	.03

[1]For 1,984 deer browse plots. An indication of dispersion and frequency.
[2]An index of plant density (based on only those plots where species occurred).
[3]Percent based on total winter weight of "choice" and "other" species.

The quantitative ranking of forbs, grasses, and legumes (based on percent occurrence in milacre subplots) compared closely with those of choice winter browse (based on amount of pounds per acre of browse in milacre subplots) in all forest types except shortleaf pine, white pine, hemlock, and pitch pine (table 4). The correlation coefficient of 0.57 between the rankings of these foods was significant at the 5-percent level.

Table 4.--Quantitative ranking of herbaceous matter and "choice" winter browse by forest type on the Chattahoochee National Forest

Forest type	"Choice" browse ranked by pounds per acre	Herbaceous matter ranked by percent occurrence[1]
Loblolly pine	1	1
Sweetgum-yellow-poplar	2	3
Oak-hickory	3	4
Oak-pine	4	5
White pine	5	11
Yellow-poplar-white pine-northern red oak	6	7
Virginia pine	7	8
Hemlock	8	14
Table-Mountain pine	9	10
Shortleaf pine	10	2
Chestnut oak	11	9
Southern scrub oak	12	12
Pitch pine	13	6
White pine-hemlock	14	13

[1]See table 6.

Browse Frequency and Density

The most frequently occurring plants included blueberry, greenbrier, red maple, mountain-laurel, hickory, blackgum, chestnut oak, and dogwood (table 3). Honeysuckle had the greatest growth density per milacre, but occurred in only 20 milacres and 6 forest types. Blueberry, in contrast was the most widely distributed species occurring on 44 percent of the plots. Greenbrier was next occurring on 35 percent of the plots. Greenbrier ranked eleventh in density, fifth in total pounds per acre, and occurred in all 14 forest types. Only eight species occurred on 10 percent or more of the plots. Collectively, they amounted to 63.1 percent of the total winter woody and leafy browse supply.

Browse Utilization

Moderately to heavily browsed (12 percent and over) "choice" plants included brook euonymus, greenbrier, allegany oilnut, blackberry, sweetshrubs, azalea, and ash. "Other" browse plants showing moderate to heavy utilization were New Jersey tea, Fraser magnolia, eastern redbud, southeast decumaria, blueberry, sweetgum, common buttonbush, and American hornbeam (table 5). Browsed "choice" woody plants were utilized 13.7 percent while browsed "other" species were utilized only 8.5 percent. Fifty-eight percent of the 82 woody plants encountered in the survey were browsed at least once.

Table 5.--Percent utilization of woody plants browsed by deer on the Chattahoochee National Forest

Species	Number of milacre subplots on which plants occurred	Percent browsed
Choice		
Brook euonymus	35	54.3
Greenbrier	696	32.5
Allegany oilnut	23	30.4
Honeysuckle	14	7.1
Blackberries	100	24.0
Sweetshrub	72	23.6
Azalea	176	12.5
Ashes	25	12.0
Sassafras	185	9.2
Dogwoods	361	8.6
Blackgum	386	5.9
Sourwood	153	5.9
Maples	561	4.6
Black locust	48	4.2
Witchhazel	25	4.0
Grapes	53	3.8
Viburnum	32	3.2
American chestnut	101	1.9
Yellow-poplar	114	1.7
Average percent browsing		13.7
Other		
New Jersey tea	40	35.0
Fraser magnolia	3	33.3
Eastern redbud	4	25.0
Southeast decumaria	46	19.5
Blueberry	882	19.2
Sweetgum	14	14.3
Rhododendron	58	8.6
Common sweetleaf	12	8.3
Birches	30	6.6
Black cherry	67	5.9
Scarlet oak	151	5.3
Chestnut	371	4.6
Sumacs	32	3.1
Mountain-laurel	398	3.0
Northern red oak	112	2.7
Oak, Other	42	2.4
Poison ivy	67	1.5
Black oak	110	.9
White oak	251	.4
Common buttonbush	3	33.3
American hornbeam	5	20.0
Silverbell	37	8.1
Elm	19	5.3
Alder	19	5.3
Hawthorn	23	4.3
Hickory	396	4.0
Hemlock	64	1.6
Average percent browsing		8.5

Remarks

Habitat conditions in north Georgia have changed markedly since the survey of Ripley and McClure in 1963. During 1963, browse species that we rate as "choice" (desirable) yielded an average of 16 pounds per acre, compared to 20 pounds contributed by "other" (undesirable) species. In the present survey, total forage yields averaged 109 pounds per acre for all types with 20 pounds contributed by "choice" plants and 89 pounds by "other" species (table 6). Thus, the quantity of "other" browse has increased considerably while that of "choice" species has increased only a little.

Table 6.--Quantity of winter food available to deer in each forest type

Forest type	Choice browse		Other browse	
	Per acre	Total	Per acre	Total
	- - - - - - - - - - - - - - Pounds - - - - - - - - - - - - - -			
White pine	15.22	217,661	101.28	1,448,405
White pine-hemlock	1.83	10,592	189.86	1,098,090
Hemlock	13.45	36,637	22.17	60,391
Loblolly pine	223.36	2,159,891	3.71	35,876
Shortleaf pine	12.29	1,004,339	68.25	4,477,390
Virginia pine	14.03	424,211	105.21	3,181.129
Pitch pine	6.52	44,401	336.36	2,290,612
Table-Mountain pine	12.86	17,515	20.16	27,458
Oak-pine	18.84	3,977,331	128.85	27,201,652
Oak-hickory	21.45	4,388,069	40.99	8,385,406
Chestnut oak	10.52	680,591	158.50	10,254,158
Yellow-poplar-white oak-northern red oak	14.78	629,081	22.04	938,089
Southern scrub	9.34	12,721	186.15	253,536
Sweetgum-yellow-poplar	37.96	155,105	35.73	145,993
Total		13,758,145[1]		60,899,004[2]

[1]Average pounds per acre of "choice" deer browse for the entire forest of 681,000 acres = 20.2.

[2]Average pounds per acre of "other" deer browse = 89.4.

In all types combined, quantity of woody browse plant material (leaves and twig ends) available to deer was 55 percent greater in summer than in winter.

Utilization ranged from 16.5 percent on "choice" species to 3.7 percent on "other" species in 1963, while in 1967 utilization ranged from 13.7 percent on "choice" species to 8.5 percent on "other" species (table 5). The 8.5-percent browsing is a substantial increase over the 3.7 percent recorded in 1963.

Based on the quantity of available "choice" browse and its degree of utilization (tables 3 and 5), it appears that range is heavily used in only a few key areas.

Table 7 shows only the occurrence of forbs, grasses, and legumes by forest type; no measure of their quantity was obtained. Forest types in which herbaceous plants most frequently occurred were loblolly pine, sweetgum-yellow-poplar, oak-hickory, and oak-pine.

Table 7.--The percent occurrence of forbs, grasses, and legumes on plots[1] by forest type on the Chattahoochee National Forest

Common name	White pine	White pine-hemlock	Hemlock	Loblolly pine	Shortleaf pine	Virginia pine	Pitch pine	Table-Mountain pine	Oak-pine	Oak-hickory	Chestnut oak	Yellow-poplar-white oak-northern red oak	Southern scrub oak	Sweetgum-yellow-poplar
	Percent occurrence													
Forbs														
Composites	--	--	--	39.0	33.2	12.5	24.0	25.0	20.0	25.8	13.8	21.0	--	--
Ferns	14.3	12.5	25.0	14.3	9.5	9.0	20.0	--	11.7	15.1	16.0	37.1	--	33.3
Euphorbs	--	--	--	--	--	--	--	--	.2	--	--	--	--	--
Cinquefoil	1.8	--	--	7.1	12.5	3.4	5.0	25.0	4.6	6.2	1.1	9.7	--	--
Violets	--	--	--	--	--	1.1	--	--	.7	1.2	.5	.8	--	--
Galax	25.0	25.0	12.5	--	1.3	4.5	10.0	--	13.0	7.2	20.2	3.2	--	--
Patridgeberry	12.5	6.2	--	21.4	9.0	2.3	--	--	4.6	1.7	4.3	2.4	25.0	25.0
Pipsissewa	--	--	--	25.0	14.6	5.7	15.0	--	8.2	16.8	8.5	7.3	--	--
Miscellaneous herbs	29.0	18.0	12.5	50.0	48.7	44.3	25.0	25.0	37.8	42.4	23.9	41.1	--	67.0
Grasses														
Beardgrass	1.8	--	--	17.8	11.2	6.8	--	--	2.6	1.0	--	--	--	--
Panicum	--	--	--	14.3	27.6	9.0	15.0	25.0	11.5	11.9	9.0	7.3	50.0	16.6
Paspalum	1.8	--	--	7.1	4.3	6.8	--	--	3.1	5.7	2.7	1.6	--	8.3
Cane	--	--	--	--	--	--	--	--	.5	.2	--	.8	--	--
Other	10.7	--	--	46.4	44.0	35.2	35.0	--	28.3	26.0	19.7	12.9	--	33.3
Legumes														
Beggarweed	--	--	--	--	.4	--	--	--	--	--	--	--	--	--
Butterflypea	--	--	--	17.8	11.2	2.3	--	--	4.1	7.7	3.2	--	--	--
Clover	--	--	--	14.4	3.0	1.1	--	--	2.3	2.3	2.1	1.6	--	16.6
Lespedeza	--	--	--	--	1.7	--	--	--	--	.3	--	--	--	--
Senna	1.8	--	--	--	.4	--	--	--	.7	--	--	--	--	--
Other	--	--	--	21.4	11.6	1.1	--	--	5.4	6.0	3.2	1.6	--	--
Fungi	--	--	--	--	--	1.1	--	--	.2	--	.5	--	--	--

[1] A milacre deer browse plot.

Ripley and McClure (1963) estimate that deer in the Southern Appalachians consume approximately 2.5 pounds per acre per day over a 100-day critical period and require 625 pounds of browse over the same period to prevent exceeding the "safe" utilization rate of 40 percent of the current annual plant growth. If these assumptions are correct, deer consume 250 pounds (total), and 375 pounds (60 percent) must be left to prevent excessive damage to available plants. When the 16 pounds per acre of desirable browse measured by Ripley and McClure (1963) are divided into 625 pounds, it is determined that 39 acres will support one deer. Adding the quantity of undesirable browse to the desirable and dividing this total (37 pounds per acre) into 625, then it is calculated that 17 acres will support one deer, assuming the undesirable browse has the same carrying capacity potential as the desirable.

More recent investigations by the Division of Forestry and Wildlife Sciences, Virginia Polytechnic Institute and State University, and the Southeastern Forest Experiment Station, however, indicate that the average deer in the pine-oak habitat of the Southern Applachians requires 3.9 pounds of forage per day to maintain body weight (120 pound deer), or 390 over the 100-day critical period. This finding indicates that 975 pounds of browse would be required per deer to stay within the "safe" utilization rate. When the 20.2 pounds per acre of "choice" browse found in this study are divided into 975 pounds, a value of 43.3 acres is found necessary to support one deer. If the 89.4 pounds of "other" browse are added to the 20.2, then 8.9 acres will support one deer. It should be kept in mind, however, that these figures are based only on the woody understory portion of deer range on the Chattahoochee National Forest. Harlow and Hooper (1971) found on analyzing 80 winter-collected rumen of white-tailed deer from the Southern Appalachians that the woody browse component (leaves and twigs) of the deer's diet amounted to 46 percent of all forage consumed. Forty-six percent of the 390 pounds totals 180 pounds, the balance of 210 pounds would typically be composed of evergreen forbs, grasses and sedges, fungi, and fruits.

Since rumen analysis studies indicate deer in the Southern Appalachians rely more heavily during the fall and winter on nonwoody than on woody forage, nonwoody forage may be the more important factor limiting population density. Since the effects of deer pressure on forest types are most easily observed and conveniently measured on the woody portion,

the woody understory is usually measured as an index to deer density. But carrying capacity cannot be based on this food source by itself.

It is impossible to measure utilization on nonwoody forage except by rumen analysis, because such forage items are usually completely consumed. There is little left on the ground to indicate how much of such forage was consumed.

Future deer forage surveys in the Southeast should stratify an area by deer density and stand condition within forest types. All forage available to deer should be measured within these additional strata. Also, before any realistic carrying capacity values can be ascertained for an area, the palatability and nutritive value of the available forages will have to be determined. Areas can possess large quantities of unpalatable or unnutritious forage. Unless these factors are considered, estimates of carrying capacity may be far too large.

SUMMARY

A sample of 496 CFI plots (1,984 milacre subplots) taken on the Chattahoochee National Forest in 17 counties of north Georgia gave estimates of browse production.

Loblolly pine, sweetgum-yellow-poplar, oak-hickory, and oak-pine forest types ranked highest in quantity and abundance of "choice" winter browse available for deer, while pitch pine, hemlock, and white pine-hemlock forest types contributed the least.

The average pounds per acre of available woody and leafy winter browse for the entire forest was 109, with 20 pounds contributed by "choice" deer foods and 89 from "other" species. Eighty-six percent of the winter browse weight in all forest types was contributed by mountain-laurel, rhododendron, blueberry, honeysuckle, greenbrier, and blackberry. Blueberry occurred most frequently (44 percent of the plots) with greenbrier second (35 percent of the plots).

Quantity (pounds per acre) of "choice" and "other" woody and leafy browse available for deer averaged for all forest types was 55 percent greater in summer than in winter.

Deer browsing intensity on "other" browse plant species was only 60 percent as high as on "choice" deer food plants.

LITERATURE CITED

Cushwa, C. T., R. L. Downing, R. F. Harlow, and D. F. Urbston
1970. The importance of woody twig ends to deer in the Southeast. USDA For. Serv. Res. Pap. SE-67, 12 p. Southeast. For. Exp. Stn., Asheville, N. C.

Harlow, R. F., and R. L. Downing
1970. Deer browsing and hardwood regeneration in the Southern Appalachians. J. For. 68:298-300.

Harlow, R. F., and R. G. Hooper
1972. Forages eaten by deer in the Southeast. Twenty-Fifth Annu. Conf. Southeast. Assoc. Game & Fish Comm. Proc. 1971:18-46.

Ripley, T. H., and J. P. McClure
1963. Deer browse resources of north Georgia. U.S. For. Serv. Resour. Bull. SE-2, 20 p. Southeast. For. Exp. Stn., Asheville, N. C.

Appendix

Table 8.--Forage plants on the Chattahoochee National Forest of Georgia and factors for converting the total length (cm) of their twigs to weight (grams)

Common name	Botanical name	Conversion factors	
		Twigs with leaves	Twigs without leaves
		Grams per centimeter	
Trees			
Ash	Fraxinus spp.	0.34920	0.06040
Beech, American	Fagus grandifolia Ehrh.	.05034	.02165
Birch	Betula spp.	.18460	.01070
Blackgum	Nyssa sylvatica Marsh.	.19790	.02176
Buckeye	Aesculus spp.	--	.11910
Cherry, Black	Prunus serotina Ehrh.	.04899	.01861
Chestnut, American	Castanea dentata (Marsh.) Borkh.	--	--
Chinkapin	Castanea spp.	.13700	.08839
Cucumbertree	Magnolia acuminata L.	.08320	.05370
Dogwood	Cornus spp.	.04030	.02114
Elm	Ulmus spp.	.01947	.00639
Hackberry	Celtis spp.	--	--
Hemlock, Eastern	Tsuga canadensis (L.) Carr.	.01430	.00330
Hickory	Carya spp.	.76420	.08370
Holly, American	Ilex opaca Ait.	.15300	.02540
Hophornbeam, Eastern	Ostrya virginiana (Mill.) K. Koch	.07870	.00820
Hornbeam, American (Blue beech)	Carpinus caroliniana Walt.	.04090	.02194
Locust, Black	Robinia pseudoacacia L.	.21090	.03080
Magnolia, Fraser	Magnolia fraseri Walt.	.08350	.05390
Maple	Acer spp.	.10630	.02897
Mulberry, Red	Morus rubra L.	.11500	.00250
Oak, Black	Quercus velutina Lam.	.23760	.05005
Oak, Chestnut	Q. prinus L.	--	--
Oak, Northern Red	Q. rubra L.	.30800	.02908
Oak, Post	Q. stellata Wangenh.	.35950	.04140
Oak, Scarlet	Q. coccinea Muenchh.	.19790	.06085
Oak, Southern Red	Q. falcata Michx.	.17430	.02897
Oak, White	Q. alba L.	.04710	.01919
Oak, Other	Quercus spp.	.60470	.08010

continued

Table 8.--Forage plants on the Chattahoochee National Forest of Georgia and factors for converting the total length (cm) of their twigs to weight (grams) (continued)

Common name	Botanical name	Conversion factors	
		Twigs with leaves	Twigs without leaves
		Grams per centimeter	
Trees			
Persimmon, Common	Diospyros virginiana L.	.07850	.01390
Pine, Eastern White	P. strobus L.	.10650	.02840
Pine, Loblolly	Pinus taeda L.	--	--
Pine, Pitch	P. rigida Mill.	.11290	.01315
Pine, Shortleaf	P. echinata Mill.	.07920	.07920
Pine, Virginia	P. virginiana Mill.	.14630	.02950
Sassafras	Sassafras albidum (Nutt.) Nees	.22260	.03360
Serviceberry	Amelanchier spp.	.18410	.01110
Silverbell	Halesia spp.	.18010	.02850
Sourwood	Oxydendrum arboreum (L.) DC.	.05909	.04064
Sweetbay	Magnolia virginiana L.	--	--
Sweetgum	Liquidambar styraciflua L.	.12730	.03770
Yellow-poplar	Liriodendron tulipifera L.	.08380	.05410
Shrubs			
Alder	Alnus spp.	.08640	.02276
Allegany oilnut	Pyrularia pubera Michx.	.10340	.07253
Azalea	Rhododendron spp. (Deciduous)	.05400	.03490
Blueberry	Vaccinium spp.	.04690	.01029
Brook euonymus	Euonymus spp.	.01244	.00750
Buttonbush, Common	Cephalanthus occidentalis L.	.11010	.02990
Chokeberry, Red	Sorbus arbutifolia (L.) Heynhold.	.03340	.01599
Cinnamon clethra	Clethra acuminata Michx.	.02310	.01732
Elder	Sambucus spp.	.06745	.02192
Hawthorn	Crataegus spp.	.03800	.01765
Hazel	Corylus spp.	.02870	.01850
Holly, Deciduous	Ilex decidua Walt.	.08510	.01397
Leucothoe	Leucothoe spp.	.11024	.04185
Mountain-ash, American	Sorbus americana Marsh.	--	--
Mountain-laurel	Kalmia latifolia L.	.19320	.02664
New Jersey tea	Ceanothus americanus L.	.02097	.01225
Plum	Prunus spp.	.08050	.02030
Redbud, Eastern	Cercis canadensis L.	.12240	.02990

continued

Table 8.--Forage plants on the Chattahoochee National Forest of Georgia and factors for converting the total length (cm) of their twigs to weight (grams) (continued)

Common name	Botanical name	Conversion factors	
		Twigs with leaves	Twigs without leaves
		Grams per centimeter	
Shrubs			
Rhododendron	Rhododendron spp. (Evergreen)	.41760	.06945
St. John's-wort	Hypericum spp.	.02243	.00657
Southeast decumaria	Hydrangea spp.	.06530	.04210
Spicebush	Lindera benzoin (L.) Blume	.03430	.01440
Sumac	Rhus spp.	.30430	.05590
Sweetleaf, Common	Symplocos tinctoria (L.) L'Her.	.05495	.02037
Sweetshrub	Calycanthus spp.	.08690	.02530
Viburnum	Viburnum spp.	.05920	.01840
Witchhazel, Common	Hamamelis virginiana L.	.16030	.03890
Yellowroot	Xanthorhiza simplicissima Marsh.	.13730	.02550
Yellowwood	Cladrastis lutea (Michx.f.) K. Koch	--	--
Vines			
Atlantic yam	Dioscorea villosa L.	--	--
Blackberry	Rubus spp.	.06280	.02420
Crossvine	Bignonia capreolata L.	--	--
Grape	Vitis spp.	.13750	.03320
Greenbrier	Smilax spp.	.08710	.04140
Japanese honeysuckle	Lonicera japonica Thunb.	.02225	.00995
Moonseed, Common	Menispermum canadense L.	--	--
Poison ivy	Rhus radicans L.	.07950	.01310
Southeast decumaria	Decumaria barbara L.	.03420	.02214
Trumpetcreeper, Common	Campsis radicans (L.) Seem.	.10187	.03425
Virginia creeper	Parthenocissus quinquefolia (L.) Planch.	.16070	.03880
Virginsbower	Clematis virginiana L.	--	--
Forbs			
Butterflypea	Centrosema spp.	--	--
Cinquefoil	Potentilla spp.	--	--
Clover	Trifolium spp.	--	--
Composites	Compositae	--	--
Euphorbs	Euphorbiaceae	--	--
Ferns	Pteridophyta	--	--
Galax	Galax aphylla L.	--	--
Lespedeza	Lespedeza spp.	--	--
Milkpea	Galactia spp.	--	--
Miscellaneous herbs		--	--

continued

Table 8.--Forage plants on the Chattahoochee National Forest of Georgia and factors for converting the total length (cm) of their twigs to weight (grams) (continued)

Common name	Botanical name	Conversion factors	
		Twigs with leaves	Twigs without leaves
		Grams per centimeter	
Forbs			
Mushrooms	Basidiomycetes	--	--
Partridgeberry	Mitchella repens L.	--	--
Pigeonwings	Clitoria spp.	--	--
Pipsissewa, Common	Chimaphila umbellata (L.) Bart.	--	--
Rhynchosia	Rhynchosia spp.	--	--
Senna	Cassia spp.	--	--
Tephrosia	Tephrosia spp.	--	--
Tickclover	Desmodium spp.	--	--
Violets	Viola spp.	--	--
Grasses			
Beardgrass	Andropogon spp.	--	--
Cane	Arundinaria spp.	--	--
Panicum	Panicum spp.	--	--
Paspalum	Paspalum spp.	--	--
Other	Gramineae	--	--

Harlow, Richard F., Paul A. Shrauder, and Monte E. Seehorn
1975. Deer browse resources of the Chattahoochee National Forest. USDA For. Serv. Res. Pap. SE-136, 16 p. Southeast. For. Exp. Stn., Asheville, N. C.

Deer browse production was estimated in the 14 major forest types on the Chattahoochee National Forest of north Georgia during the winter. The average yield of browse for all forest types was 109 pounds per acre, with 20 pounds contributed by "choice" deer food plants and 89 from "other" species.

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DA Forest Service Research Paper SE-137 July 1975

Deer Browse Resources of the Oconee National Forest

by

Richard F. Harlow
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Deer Browse Resources of the Oconee National Forest

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Deer browse, including shrub and tree foliage and woody twig ends, was surveyed on the Oconee National Forest during the fall and winter of 1967. Yields, frequency, density, and utilization of browse were estimated for each forest type. The results are presented here to help evaluate the relative values of the forest types as deer range and to determine which types need management.

This 96,056-acre national forest is in the central part of the Piedmont Plateau Province and occupies portions of Jasper, Putnam, Greene, Jones, Oglethorpe, and Oconee Counties in Georgia (fig. 1).

Figure 1.--Area in central Georgia sampled in browse survey.

The northern section of the forest is quite hilly, while the southern section has broad interstream areas of gently rolling hills. Elevations vary from 600 to 1,200 feet. Though the soils are generally rich, they lack stability; consequently, erosion and depleted soil fertility forced abandonment of farms there in the early to mid-1900's. Pines and hardwoods quickly seeded in and many freshly abandoned sites were invaded by vines such as Japanese honeysuckle and greenbrier (Walker and Perkins 1958).

Since the sampling units were on permanent Continuous Forest Inventory (CFI) plots, it will be convenient to redescribe browse conditions and determine trends in future surveys.

METHODS

Fieldwork was performed by a contracted private crew. Four milacre subplots were randomly selected for sampling at each CFI plot. Data collected on the four subplots included:

1. Number of plants of each woody species rooted on the subplot.

2. Number of lateral and terminal growing points and the average length of current-season twig growth up to 4.5 feet high for each species.

3. Evidence of recent deer utilization for each species.

4. Presence of herbaceous vegetation was noted by species and evidence of utilization recorded.

Representative samples of browse were collected on the Oconee National Forest from the fall of 1966 up to the spring of the 1967 growing season, ovendried, weighed, and measured. From these data, ratios were obtained for converting total length of new growth to weight. Ratios of twig length to twig weight, with and without foliage, were used to calculate the weights reported in this Paper. The field crew was instructed on plant identification and other necessary measurement procedures.

Each browse plant was assigned one of the following classes:

Choice: Plants consistently utilized throughout the year.

Other: Plant utilization inconsistent or unknown.

Plants were assigned to these preference classes based on analysis of rumen samples of white-tailed deer and on deer browse studies in the Southern Appalachians by Harlow and Downing (1970); Cushwa et al. (1970); and Harlow and Hooper (1971).

Sampling units (subplot data) were summarized by class, and the average for each timber inventory plot was viewed as a single observation (cluster sample). Browse weight, percent occurrence, and utilization were then statistically examined for differences between major forest types.

Sampling strata included nine forest types (Society of American Foresters 1967), which are listed in table 1 along with the number of plots taken in each type. Sixty-five percent of the 572 milacre plots were in the loblolly pine type, 14 percent in the shortleaf pine type, and 11 percent in the oak-pine type. The remaining 10 percent were distributed between six other closely associated forest types.

Common and scientific names of plants found in the survey are listed in the Appendix.

Table 1.--List of forest types showing number of plots sampled and number of plots needed

Forest type	Area in type	Milacre plots sampled	Total plots needed[1]
	Acres	Number	Number
Loblolly pine	62,446	372	27
Shortleaf pine	13,449	80	15
Oak-pine	11,421	68	47
Sweetgum-yellow-poplar	2,017	12	27
Elm-ash-cottonwood	2,017	12	21
Oak-hickory	2,017	12	9
Yellow-poplar-white oak-northern red oak	1,345	8	45
Virginia pine	672	4	7
Slash pine	672	4	23
Total	96,056	572	221

[1]To detect a 50-percent difference in plant weights per milacre plot at the 5-percent level.

RELIABILITY OF THE DATA

Sampling error formula $N = \frac{s^2 t^2}{d^2}$ from Snedecor (1946, p. 456-458),

Where:

N = number of plots required

s = standard deviation of the variance

t = normal deviate at confidence limit level and degrees of freedom (based on initial sample size)

d = margin of error (arithmetic mean of the total times designated percent accuracy).

We had hoped for an error small enough to detect 50-percent changes if they occurred in plant weights per milacre plot when tested at the 5-percent level. Only four types were sampled sufficiently to meet this criterion. These types, loblolly pine, shortleaf pine, oak-pine, and oak-hickory, however, constituted 93 percent of the total acreage on the Oconee National Forest (table 1).

RESULTS AND DISCUSSION

Browse Yields

Pounds per acre of winter browse on the Oconee National Forest averaged 128 for "choice" species and 14 for "other" species (table 2). On a per acre basis, sweetgum-yellow-poplar produced the most "choice" browse, Virginia pine second, and loblolly pine third (table 3).

Table 2.--Quantity of winter food available to deer in each forest type

Forest type	"Choice" browse[1]		"Other" browse[2]	
	Average	Total	Average	Total
	Pounds/acre			
Loblolly pine	154	9,599,823	17	1,038,477
Oak-pine	74	840,129	10	111,355
Sweetgum-yellow-poplar	346	696,873	11	22,671
Shortleaf pine	42	563,111	6	86,611
Elm-ash-red maple	116	234,254	1	2,420
Virginia pine	320	215,128	64	42,706
Slash pine	131	87,783	23	15,375
Yellow-poplar-white oak-northern red oak	48	64,210	3	4,008
Oak-hickory	15	30,558	16	32,232
Total		12,331,869		1,355,855

[1]Average pounds per acre of "choice" deer browse for the entire forest (96,056 acres) = 128.

[2]Average pounds per acre of "other" deer browse for the entire forest = 14.

Table 3.--Air-dry pounds per acre of winter deer browse, percent woody plants browsed, and number of plant species present by forest type on the Oconee National Forest. Forest types are listed in order of importance as producers of "choice" deer food

Forest type	Browse class	Plant species occurring on plots	Subplots having plants browsed	Winter browse in class	All winter browse with 95-percent confidence limits
		Number	Percent	Pounds/acre	Pounds/acre
Sweetgum-yellow-poplar	Choice	8	11.1	346[1]	357 ± 267
	Other	14	4.1	11	
Virginia pine	Choice	5	33.3	320[2]	384 ± 263
	Other	4	33.3	64	
Loblolly pine	Choice	21	7.4	154[3]	171 ± 46
	Other	41	1.7	17	
Slash pine	Choice	4	0	131[1]	154 ± 406
	Other	6	0	23	
Elm-ash-red maple	Choice	8	5.9	116[1]	117 ± 74
	Other	7	0	1	
Oak-pine	Choice	17	4.0	74[1]	84 ± 33
	Other	30	1.2	10	
Yellow-poplar-white oak-northern red oak	Choice	6	0	48[4]	51 ± 60
	Other	10	0	3	
Shortleaf pine	Choice	13	5.5	42[1]	48 ± 18
	Other	22	1.8	6	
Oak-hickory	Choice	9	17.8	15[2]	31 ± 7
	Other	14	8.9	16	

[1]Predominantly Japanese honeysuckle (Lonicera japonica Thunb.).
[2]Predominantly greenbrier (Smilax spp.).
[3]Predominantly Japanese honeysuckle (Lonicera japonica Thunb.) and blackberry (Rubus spp.).
[4]Predominantly grape (Vitis spp.) and Japanese honeysuckle (Lonicera japonica Thunb.).

The small acreage of Virginia pine (674) negated, to some extent, the value of this type for deer. The third most productive type, loblolly pine, covers 65 percent of the forest and must be considered the most important for deer. Eighty-three percent of the "choice" winter browse weight in these three types was contributed by Japanese honeysuckle, greenbrier, and blackberry--all considered important deer foods (table 4).

Table 4.--Density ratings of the major browse plants and their relative quantities based on percent of total pounds per acre, Oconee National Forest

Species	Plots plant occurred on		Plant density index[1]	Forest types found on	Proportion of total browse weight[2]
	Number[3]	Percent		Number	Percent
Japanese honeysuckle (Lonicera japonica Thunb.)	228	39.8	1,580.0	8	49.40
Greenbrier (Smilax spp.)	269	47.0	62.0	8	27.10
Blackberry (Rubus spp.)	75	13.1	359.4	6	6.90
Blueberry (Vaccinium spp.)	49	8.5	804.9	5	4.70
Grape (Vitis spp.)	113	19.7	61.5	6	2.70
Sweetgum (Liquidambar styraciflua L.)	142	24.8	20.8	5	2.20
Yellow jessamine (Gelsemium sempervirens (L.) Ait. f.)	41	7.2	118.8	3	1.70
Virginia creeper (Parthenocissus quinquefolia (L.) Planch.)	97	16.2	196.1	7	.80
Loblolly pine (Pinus taeda L.)	143	25.0	11.5	3	.50
Crossvine (Bignonia capreolata L.)	5	.9	167.6	2	.40
Eastern white pine (Pinus strobus L.)	1	.2	83.0	1	.40
Flowering dogwood (Cornus florida L.)	100	17.4	23.8	5	.30
Maple (Acer spp.)	112	19.6	43.2	8	.30
Alabama supplejack (Berchemia scandens (Hill) K. Koch)	19	3.3	261.2	4	.30
Poison ivy (Rhus radicans L.)	121	21.2	158.7	8	.30
Trumpetcreeper, Common (Campsis radicans (L.) Seem.)	24	4.2	293.2	3	.20
Shortleaf pine (Pinus echinata Mill.)	72	12.6	17.6	4	.20
Hawthorn (Crataegus spp.)	93	16.2	16.1	4	.20
Blackgum (Nyssa sylvatica Marsh.)	48	8.4	17.0	6	.10
Southern red oak (Quercus falcata Michx.)	69	12.0	16.3	5	.10

continued

Table 4.--Density ratings of the major browse plants and their relative quantities based on percent of total pounds per acre, Oconee National Forest (continued)

Species	Plots plant occurred on		Plant density index[1]	Forest types found on	Proportion of total browse weight[2]
	Number[3]	Percent		Number	Percent
Sumac (Rhus spp.)	52	9.0	8.4	3	0.10
Virginia pine (Pinus virginiana Mill.)	2	.3	208.0	2	.10
Hickory (Carya spp.)	50	8.7	30.7	7	.10
American hornbeam (Carpinus caroliniana (Walt.)	9	1.6	58.0	4	.10
Elm (Ulmus spp.)	152	26.5	17.2	6	.09
Brook euonymus (Euonymus americanus L.)	24	4.2	119.4	4	.06
Black cherry (Prunus serotina Ehrh.)	63	11.0	34.4	4	.05
Eastern redcedar (Juniperus virginiana L.)	7	1.2	19.0	3	.04
White oak (Quercus alba L.)	42	7.3	24.7	5	.03
St. John's-Wort (Hypericum spp.)	12	2.1	26.6	3	.02
New Jersey tea (Ceanothus americanus L.)	9	1.6	237.0	4	.02
Yellow-poplar (Liriodendron tulipifera L.)	18	3.1	15.5	4	.01
Sourwood (Oxydendrum arboreum (L.) DC.	5	.9	7.0	1	.01
Serviceberry (Amelanchier spp.)	1	.2	83.0	1	.01
Sassafras (Sassafras albidum (Nutt.) Nees)	17	2.9	39.1	5	.01
Other oak (Quercus spp.)	3	.5	13.0	2	.01
Persimmon (Diospyros spp.)	16	2.8	19.2	3	.01
Plum (Prunus spp.)	26	4.5	9.9	2	.01
Water oak (Quercus nigra L.)	16	2.8	11.9	3	.01
American holly (Ilex opaca Ait.)	2	.03	2.5	1	.01

[1]An index of plant density.
[2]Percent based on total winter weight of choice and other species.
[3]Milacre deer browse plot. An index of dispersion and frequency.

Twenty-six percent of the forest was composed of oak-pine and shortleaf pine forest types (table 1). Both were comparatively low in production of deer foods, ranking sixth and eighth in average pounds per acre. Since these types were second and third in acreage (table 1) and comprise a sizable portion of the forest, it may be important for biologists to emphasize management of these two types for deer. The predominant "choice" deer food present in the oak-pine and shortleaf pine forest types was Japanese honeysuckle (table 3).

Japanese honeysuckle and greenbrier, two of the most important winter deer forages, occurred in eight of the nine forest types and on 39.8 and 47.0 percent, respectively, of the 572 milacre survey plots (table 4). These two plants contributed 77 percent of the total pounds per acre of winter browse produced by all major browse plants measured (table 4). The next two most productive contributors were blackberry and blueberry, which together produced 11.6 percent of the total pounds per acre of forage. Eighty-nine percent of the available browse was provided by these four plants. Browse plants of greatest density per milacre plot (table 4) were Japanese honeysuckle, blueberry, and blackberry, with honeysuckle density considerably exceeding that of any other plant.

Herbaceous plants are a necessary component of desirable range for deer. Loblolly, shortleaf, and oak-pine types provided deer on the Oconee Area with a greater variety of herbaceous plant species than did the other types (table 5).

Browse Utilization

Average utilization was 10.2 percent for all "choice" browse plants and 4.9 percent for "other" species (table 6). These values indicate light utilization of both browse classes. Greenbrier plants were utilized 20.4 percent of the time. Percent browsing on Japanese honeysuckle was 3.5, extremely light; however, browsing on this particular shrub is less evident than on most because of the close growing foliage. Browsing was detected on 50 percent of the euonymus plants which are also considered a "choice" food. Blueberry was the only woody plant not in the "choice" category which was heavily utilized (20.4 percent), and it also occurred frequently. Forty-five of the 75 woody plant species identified in the survey were not browsed.

Remarks

Based on degree of browsing and quantity of "choice" browse plants available, the Oconee National Forest appears to be in exceptionally good condition for deer. The Oconee Forest contains far more food than the Chattahoochee National Forest, where a similar inventory was conducted. The weight of available "choice" browse averaged only 20 pounds per acre on the Chattahoochee and 128 on the Oconee.

The forest types were ranked from first to ninth according to their value to deer considering acres in type, average pounds per acre of "choice" winter browse, percent occurrence of forbs, grasses, and legumes, and variety of "choice" browse plants occurring in a type (table 7). The four criteria were accorded equal importance in assigning an overall ranking of the forest types. The forest type with the lowest sum of rankings was judged to be most productive for deer. In overall rank, loblolly pine placed first, shortleaf pine second, and oak-pine third.

Table 5.--Percent occurrence of forbs, grasses, and legumes on milacre plots by forest type, Oconee National Forest

Species	Slash pine	Loblolly pine	Shortleaf pine	Virginia pine	Oak-pine	Oak-hickory	Yellow-poplar-white oak-northern red oak	Sweetgum-yellow-poplar	Elm-ash-cottonwood
	Percent occurrence								
Forbs									
Cinquefoil (Potentilla spp.)	--	11.8	30.0	--	5.8	8.3	--	8.3	8.3
Composites	--	4.0	12.5	--	23.5	--	37.5	8.3	58.3
Euphorbs	--	--	--	--	1.5	--	--	--	--
Ferns	--	2.7	1.2	25.0	19.1	16.6	--	--	--
Pipsissewa (Chimaphila spp.)	--	13.4	16.2	--	5.8	--	--	--	--
Violets (Viola spp.)	--	.3	1.2	--	--	16.6	--	--	--
Miscellaneous	5.0	61.5	63.7	75.0	52.9	50.0	75.0	83.3	83.3
Grasses									
Beardgrass (Andropogon spp.)	--	20.4	13.7	25.0	--	--	--	--	--
Cane (Arundinaria gigantea (Walt.) Muhl.)	--	1.3	--	--	7.3	--	--	--	--
Panicum (Panicum spp.)	--	7.5	15.0	--	10.3	16.6	12.5	--	8.3
Paspalum spp.	--	17.7	15.0	50.0	7.3	33.2	--	--	8.3
Other	15.0	63.9	56.2	50.0	35.2	75.0	37.5	58.3	100.0
Legumes									
Atlantic pigeonwings (Clitoria mariana L.)	5.0	61.8	12.5	--	11.7	--	--	8.3	--
Clover (Trifolium spp.)	--	17.7	20.0	--	1.5	-	--	--	--
Lespedeza (Lespedeza spp.)	--	5.1	3.7	25.0	--	--	--	--	--
Partridge-pea (Cassia fasciculata Michx.)	--	2.1	--	--	--	8.3	--	--	--
Tephrosia (Tephrosia spp.)	--	.6	--	--	--	--	--	--	--
Tickclover (Desmodium spp.)	--	.3	--	--	--	--	--	--	--
Other	--	20.7	13.7	--	14.7	16.6	25.0	--	8.3

Table 6.--Utilization record of all woody plants browsed, Oconee National Forest

Species	Plots occupied	Occupied plots browsed	Proportion of plots browsed
	- - - Number - - -		Percent
Choice			
Alabama supplejack (Berchemia scandens (Hill) K. Koch)	19	2	10.5
Ash (Fraxinus spp.)	29	1	3.4
Black locust (Robinia pseudoacacia L.)	1	1	100.0
Blackberry (Rubus spp.)	75	8	10.6
Blackgum (Nyssa sylvatica Marsh.)	48	3	5.8
Brook euonymus (Euonymus americanus L.)	24	12	50.0
Flowering dogwood (Cornus florida L.)	100	9	9.0
Grape (Vitis spp.)	113	1	.9
Greenbrier (Smilax spp.)	269	55	20.4
Japanese honeysuckle (Lonicera japonica Thunb.)	228	8	3.5
Maple (Acer spp.)	112	1	.9
Sassafras (Sassafras albidum (Nutt.) Nees)	17	1	5.9
Sweet shrub, Common (Calycanthus floridus L.)	2	1	50.0
Viburnum (Viburnum spp.)	3	2	66.6
Yellow jessamine (Gelsemium sempervirens (L.) Ait. f.)	41	6	14.6
Average percent browsing			10.2
Other			
Black cherry (Prunus serotina Ehrh.)	63	4	6.3
Black walnut (Juglans nigra L.)	2	1	50.0
Blueberry (Vaccinium spp.)	49	10	20.4
Eastern redcedar (Juniperus virginiana L.)	7	1	14.3
Elm (Ulmus spp.)	152	3	1.9
Hawthorn (Crataegus spp.)	93	5	5.4
Hickory (Carya spp.)	50	1	2.0
Pawpaw (Asimina triloba (L.) Dunal	2	1	50.0
Plum (Prunus spp.)	26	2	7.7
Poison ivy (Rhus radicans L.)	121	1	.8
Southern red oak (Quercus falcata Michx.)	69	3	4.3
Sumac (Rhus spp.)	52	4	7.7
Sweetgum (Liquidambar styraciflua L.)	142	2	1.4
Trumpetcreeper, Common (Campsis radicans (L.) Seem.)	24	3	12.5
Virginia pine (Pinus virginiana Mill.)	2	1	50.0
Average percent browsing			4.9

Table 7.--Forest type forage rating for white-tailed deer on the Oconee National Forest

Forest type	Acres in type	Average pounds per acre "choice" browse	Percent occurrence of forbs, grasses, and legumes	Number "choice" browse plants	Total	Rank
Loblolly pine	1	3	1	1	6	1
Shortleaf pine	2	8	2	3	15	2
Oak-pine	3	6	6	2	17	3
Elm-ash-red maple	4	5	3	6	18	4
Sweetgum-yellow-poplar	4	1	8	5	18	4
Virginia pine	8	2	4	8	22	6
Oak-hickory	4	9	5	4	22	6
Yellow-poplar-white oak-northern red oak	7	7	7	7	28	8
Slash pine	9	4	9	9	31	9

Studies by Harlow and Hooper (1971) disclosed that the leaves and twigs of woody plants made up an average of 46 percent of the total annual diet of white-tailed deer (Odocoileus virginianus) in the Southeast. This percentage ranged from a low of 33 during the fall fruiting period to a high of 56 in the spring when most annual growth occurs. Thus, attempts to relate browse abundance alone to the carrying capacity of the habitat could be misleading because other foods are cumulatively more important. However, since 100 percent consumption often makes it impossible to measure utilization on nonwoody forage, sampling the woody understory is presently a more accurate and measurable means of detecting deer densities.

SUMMARY

A sample of 143 CFI (572 milacre subplots) taken in six counties of central Georgia gave estimates of woody and leafy browse production on the Oconee National Forest.

An average of 142 pounds per acre of winter browse was available on the 96,056-acre area; 128 pounds were on "choice" deer food plants. The two choice food plants, Japanese honeysuckle and greenbrier, contributed 76.5 percent of the available winter browse.

Deer utilization on woody plants was usually light in all forest types.

Quantity of "choice" and "other" woody browse available to deer was only 3.9 percent greater in summer than in winter due to the abundance of the evergreen woody browse plants greenbrier and Japanese honeysuckle.

The nine forest types were ranked according to their value to deer based on acres in type, pounds per acre of "choice" browse, percent occurrence of forbs, grasses and legumes, and number of "choice" browse plants. The loblolly pine type ranked first, shortleaf second, and oak-pine third.

Based on quantity of available browse, the Oconee National Forest is in exceptionally good condition for deer at this time.

LITERATURE CITED

Cushwa, C. T., R. L. Downing, R. F. Harlow, and D. F. Urbston
1970. The importance of woody twig ends to deer in the Southeast. USDA For. Serv. Res. Pap. SE-67, 12 p. Southeast. For. Exp. Stn., Asheville, N.C.

Harlow, R. F., and R. L. Downing
1970. Deer browsing and hardwood regeneration in the Southern Appalachians. J. For. 68:298-300.

Harlow, R. F., and R. G. Hooper
1972. Forages eaten by deer in the Southeast. Twenty-Fifth Annu. Conf. Southeast. Assoc. Game & Fish Comm. Proc. 1971:18-46.

Snedecor, G. W.
1946. Statistical methods. 4th ed. 485 p. Iowa State Coll. Press. Ames, Iowa.

Society of American Foresters
1967 (rev.). Forest cover types of North America (exclusive of Mexico). Washington, D.C. 67 p.

Walker, L. C., and H. F. Perkins
1958. Forest soils and silviculture in Georgia. Univ. Ga. Sch. For. & Coll. Agric., Athens. Rep. 4, 36 p.

APPENDIX

Table 8.--List of forage plants found on the Oconee National Forest in Georgia

Common name	Scientific name
Trees	
Ash	Fraxinus spp.
Blackgum	Nyssa sylvatica Marsh.
Boxelder	Acer negundo L.
Buckeye	Aesculus spp.
Cherry, Black	Prunus serotina Ehrh.
Dogwood	Cornus spp.
Elm	Ulmus spp.
Fringetree	Chionanthus virginicus L.
Hackberry	Celtis spp.
Hickory	Carya spp.
Holly, American	Ilex opaca Ait.
Honeylocust	Gleditsia triacanthos L.
Hophornbeam, Eastern	Ostrya virginiana (Mill.) K. Koch
Hornbeam, American (Blue beech)	Carpinus caroliniana Walt.
Locust, Black	Robinia pseudoacacia L.
Maple	Acer spp.
Mulberry, Red	Morus rubra L.
Oak, Black	Quercus velutina Lam.
Oak, Chestnut	Q. prinus L.
Oak, Northern red	Q. rubra L.
Oak, Post	Q. stellata Wangenh.
Oak, Scarlet	Q. coccinea Muenchh.
Oak, Southern Red	Q. falcata Michx.
Oak, Water	Q. nigra L.
Oak, White	Q. alba L.
Oak, Willow	Q. phellos L.
Oak, Other	Quercus spp.
Persimmon, Common	Diospyros virginiana L.
Pine, Eastern white	Pinus strobus L.
Pine, Loblolly	P. taeda L.
Pine, Shortleaf	P. echinata Mill.
Pine, Slash	P. elliottii Engelm.
Pine, Virginia	P. virginiana Mill.
Redcedar, Eastern	Juniperus virginiana L.
Sassafras	Sassafras albidum (Nutt.) Nees
Serviceberry	Amelanchier spp.
Silverbell	Halesia spp.
Sourwood	Oxydendrum arboreum (L.) DC.
Sweetgum	Liquidambar styraciflua L.

continued

Table 8.--List of forage plants found on the Oconee National Forest in Georgia (continued)

Common name	Scientific name
Walnut, Black	Juglans nigra L.
Yellow-poplar	Liriodendron tulipifera L.
Shrubs	
American beautyberry	Callicarpa americana L.
Azalea (Deciduous)	Rhododendron spp.
Blueberry	Vaccinium spp.
Buttonbush, Common	Cephalanthus occidentalis L.
Euonymus	Euonymus spp.
Hawthorn	Crataegus spp.
Hydrangea	Hydrangea spp.
New Jersey tea	Ceanothus americanus L.
Pawpaw	Asimina spp.
Pear	Pyrus spp.
Plum	Prunus spp.
Redbud, Eastern	Cercis canadensis L.
St. John's-Wort	Hypericum spp.
Spicebush	Lindera benzoin (L.) Blume
Sumac	Rhus spp.
Sweetshrub	Calycanthus spp.
Viburnum	Viburnum spp.
Virginia sweetspire	Itea virginica L.
Witchhazel	Hamamelis virginiana L.
Yellowroot	Xanthorhiza simplicissima Marsh.
Vines	
Alabama supplejack	Berchemia scandens (Hill) K. Koch
Blackberry	Rubus spp.
Crossvine	Bignonia capreolata L.
Grape	Vitis spp.
Greenbrier	Smilax spp.
Japanese honeysuckle	Lonicera japonica Thunb.
Moonseed, Common	Menispermum canadense L.
Poison ivy	Rhus radicans L.
Southeast decumaria	Decumaria barbara L.
Trumpetcreeper, Common	Campsis radicans (L.) Seem.
Virginiacreeper	Parthenocissus quinquefolia (L.) Planch.
Virginsbower	Clematis virginiana L.
Yam vine, Wild	Dioscorea quaternata (Walt.) J. F. Gmel.
Yellow jessamine	Gelsemium sempervirens (L.) Ait. f.
Forbs	
Cinquefoil	Potentilla spp.

continued

Table 8.--List of forage plants found on the Oconee National Forest in Georgia (continued)

Common name	Scientific name
Composites	Compositae
Euphorbs	Euphorbiaceae
Ferns	Pteridophyta
Miscellaneous herbs	
Violets	*Viola* spp.
Grasses	
Beardgrass	*Andropogon* spp.
Giant cane	*Arundinaria gigantea* (Walt.) Muhl.
Panicum	*Panicum* spp.
Paspalum	*Paspalum* spp.
Other	Gramineae
Legumes	
Butterflypea	*Centrosema* spp.
Clover	*Trifolium* spp.
Lespedeza	*Lespedeza* spp.
Partridgepea	*Chamaecrista* spp.
Pigeonwings	*Clitoria* spp.
Tephrosia	*Tephrosia* spp.
Tickclover	*Desmodium* spp.

Harlow, Richard F., Paul A. Shrauder, and Monte E. Seehorn

1975. Deer browse resources of the Oconee National Forest. USDA For. Serv. Res. Pap. SE-137, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

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A Technique for Comparing Thinning Schedules for Natural Slash Pine Stands

by
Frank A. Bennett

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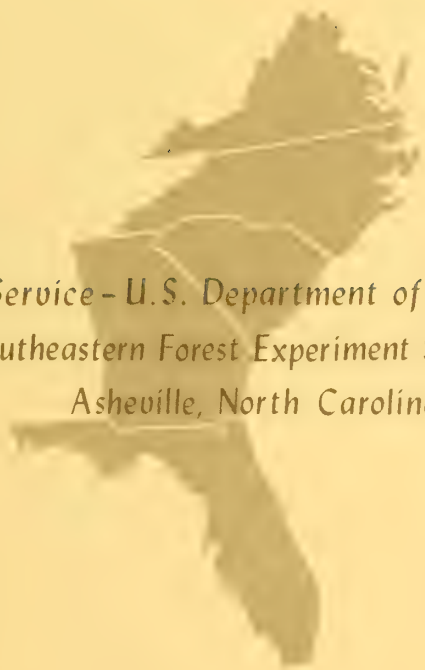

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A Technique for Comparing Thinning Schedules for Natural Slash Pine Stands

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Cubic and board-foot yields for managed natural slash pine stands were published in 1970.[1] Included in the document were yield estimates in cubic feet, board feet, and square feet of basal area projected from known stand conditions. These estimates were developed from data gathered from a series of plots thinned to specified residual densities at 5-year intervals. This paper illustrates how the equation developed from these data can be employed to devise and compare management regimes for natural slash pine stands.

METHODS

The yield and projection equations referred to are:

$$LnY_2 = 5.98812 - \frac{121.713}{S} - \frac{19.758}{A_2} + 4.632\left(1 - \frac{A_1}{A_2}\right) + 0.89683(LnB_1)\left(\frac{A_1}{A_2}\right) \quad (1)$$

$$LnY = 5.98812 - \frac{121.713}{S} - \frac{19.758}{A} + 0.89683\,(LnB) \quad (2)$$

$$LnB_2 = LnB_1\left(\frac{A_1}{A_2}\right) + 5.1649\left(1 - \frac{A_1}{A_2}\right) \quad (3)$$

and $$BFY = 1236.125 - 186.16011(B) + 7.31406(CFV) \quad (4)$$

where Ln = natural logarithm

A = any given age in years

B = any given basal area in square feet

A_1 = initial age in years

[1] Bennett, Frank A. 1970. Variable-density yield tables for managed stands of natural slash pine. USDA For. Serv. Res. Note SE-141, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

A_2 = terminal age in years

B_1 = basal area at A_1

B_2 = basal area at A_2

CFV = cubic-volume stocking

S = site index (50-year basis)

Y = cubic-foot yield at A or A_1

Y_2 = projected cubic-foot yield at A_2

and BFY = board-foot yield

These equations permit us to:

1. Project future cubic and board-foot yields based on present stand conditions.
2. Estimate future basal area stockings from present stand conditions.
3. Thin a stand to a specified density and forecast future yield from residual stand conditions.

Although the projection equation (1) permits us to predict yields at future dates after thinning--an extremely useful capability--the projection scheme provides no method of estimating the cubic volume removed by thinning. This defect is not critical in "on the ground" management because the forester can determine the volume that has been marked for cutting. However, for planning purposes it is important to have some method of estimating volume that will be removed in future thinnings.

A reliable technique is available. It involves finding the ratio of cubic feet of merchantable volume: square feet of basal area in the stand as a whole, and then applying a correction factor to account for the types of trees cut and left in thinning. For example, published yield estimates[2] show that site 100 at age 20 and containing 100 square feet of basal area stocking yields 2,733 cubic feet. For each square foot of basal stocking there are 27.33 cubic feet of merchantable volume. Now, if we cut this stand to 75 square feet of basal area and remove a proportional amount of basal area from each diameter class (if a particular diameter class contains 20 percent of the total basal area stocking, 20 percent of the basal area cut will come from that class), the amount of volume removed would equal 25 (the total amount of basal area cut) times 27.33 (the number of cubic feet per square foot of basal area stocking), or 683 cubic feet. However, we normally thin from below, i.e.; concentrate our cut in the smaller trees. (This was the technique employed on the research plots from which the basic yield estimates were produced.) Thus, the cubic volume harvested per square foot of basal area removed is lower than the ratio for the entire stand. For example, the number of cubic feet per square foot of basal area for 5-inch trees varies from 11.0 to 24.2, depending upon height, whereas the range for 15-inch trees is from 30.6 to 46.3 (table 1).

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[2] Ibid.

Table 1.--Cubic feet[1] per square foot of basal area ratios for natural slash pine[2]

D.b.h. (inches)	Total height (feet)						
	30	40	50	60	70	80	90
	Cubic feet/square foot						
5	11.0	13.9	19.1	24.2	--	--	--
7	--	17.2	22.4	27.7	--	--	--
9	--	18.8	24.0	29.2	34.4	--	--
11	--	--	24.7	29.8	35.2	40.2	--
13	--	--	25.1	30.3	35.5	40.8	46.0
15	--	--	--	30.6	35.8	41.1	46.3

[1] Cubic volume outside bark to a 4-inch top.

[2] Cooper, Robert W., and David F. Olson, Jr. 1958. Volume determinations for second-growth slash and longleaf pine in Northeast Florida. USDA For. Serv. Stn. Pap. 92. 11 p. Southeast. For. Exp. Stn., Asheville, N.C.

Applying selective thinnings from below to available slash pine plantation diameter distributions shows that for different age-site-density combinations and thinning levels, the cubic feet per square foot of basal area ratios as percents of those for entire stands do not vary greatly (table 2). For a thinning that removes 21.6 percent of the basal area (cutting option I) from a plantation on site 70 at age 16, the cubic feet per square foot of basal area ratio for the cut trees (18.75) is 92.2 percent of the ratio for the entire stand. For a thinning that removes 31.3 percent of the basal area stocking (cutting option II), the cubic feet: basal area ratio (19.00) is 93.6 percent of that for the whole stand. The two plantations on site 60, although differing in age, number of trees per acre, and basal area stocking, show similar results when thinned from below.

These data indicate that any chosen percentage of the stand volume-basal area stocking ratio applied to a given amount of basal area removed in a cut will specify a particular distribution of the cut throughout the stand diameter range. In general, using 90 to 94 percent of the cubic feet per square foot of basal area stocking ratio times the square feet of basal area cut will denote a selective thinning from below; i.e., the cut will concentrate most heavily in the smaller diameter classes but extend into the larger sizes. Percentages below this range indicate little to no cutting in the larger diameter classes, and percentages above the specified range suggest a thinning rather evenly distributed throughout the diameter range. (Landowners or forest managers with available stand tables can, of course, derive percentage correction factors from their own data.)

Table 2.- Cubic feet per square foot of basal area ratios are less for cut trees than for the entire stand in selectively thinned slash pine plantations

SITE 70 (25-YEAR BASIS) SITE 80 (25-YEAR BASIS)

D.b.h. class (inches)	Initial stand - age 16			Thinning schedule						Plantation 1 - age 20						Plantation 2 - age 16					
				Option I			Option II			Initial stand			Cut			Initial stand			Cut		
	Trees	Basal area	Volume	Trees	Basal area	Volume	Trees	Basal area	Volume	Trees	Basal area	Volume	Trees	Basal area	Volume	Trees	Basal area	Volume	Trees	Basal area	Volume
	No.	Sq ft	Cu ft	No.	Sq ft	Cu ft	No.	Sq ft	Cu ft	No.	Sq ft	Cu ft	No.	Sq ft	Cu ft	No.	Sq ft	Cu ft	No.	Sq ft	Cu ft
1	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0		0	0	0	0	0	0	0	1	.02	6	0	0	0	1	.02	0	0	0	0
3	6	0.29	0	0	0	0	0	0	0	10	.49	0	0	0	0	26	.79	0	0	0	0
4	33	2.83	0	0	0	0	0	0	0	30	3.40	0	0	0	0	7	4.38	0	0	0	0
5	78	10.23	142	41	5.56	76	55	7.50	104	77	10.50	144	46	6.27	86	104	14.19	195	69	9.42	129
6	112	21.60	303	46	8.83	158	60	11.78	211	109	21.46	379	60	9.81	174	139	27.42	379	50	6.81	148
7	124	33.15	681	30	8.02	169	43	11.49	236	118	31.54	648	23	6.61	126	113	31.54	645	20	5.43	92
8	99	34.56	784	10	3.49	79	20	6.98	158	96	33.51	752	5	2.74	47	65	22.69	486	5	1.76	44
9	47	20.76	499	3	1.33	32	4	1.77	42	46	20.32	484	3	1.33	32	10	4.42	87	0	0	0
10	4	2.18	58	0	0	0	0	0	0	4	2.18	58	0	0	0	0	0	0	0	0	0
Total	500	126.04	2,557	129	27.26	510	182	39.52	751	500	123.36	2,465	128	26.35	481	400	104.15	1,602	135	25.09	361

Computation of cubic feet per square foot of basal area:

Initial stand: $\frac{2,557}{126.04} = 20.29$

Option I: $\frac{510}{27.26} = 18.71$

Option II: $\frac{751}{39.52} = 19.00$

Cut tree ratio as a percent of the stand ratio:

$\frac{18.71}{20.29} = 92.2$ percent

$\frac{19.00}{20.29} = 93.6$ percent

Computation of cubic feet per square foot of basal area:

Plantation 1

Initial stand: $\frac{2,465}{123.36} = 19.98$

Cut: $\frac{481}{26.35} = 18.25$

Plantation 2

Initial stand: $\frac{1,602}{104.15} = 15.38$

Cut: $\frac{361}{25.09} = 14.39$

Cut tree ratio as a percent of the stand ratio:

$\frac{18.25}{19.98} = 91.3$ percent

$\frac{14.39}{15.38} = 93.6$ percent

Applying this technique, and using 92 percent of the stand volume: basal area ratio to determine the cut volume, a thinning regime can be developed as illustrated in table 3. As pointed out, the volume removed will vary with the distribution of the cut among the diameter classes. Thus, the illustration represents one possible thinning regime. This scheme can be used to set up any type of thinning schedule. The cut volumes determined by this technique include no error beyond that inherent in estimating and projecting yields.

Utilizing equations (2), (3), and (4), board-foot volumes removed in thinning can also be estimated (table 4).

Table 3.--Projected cubic yields after thinning for site 100

Age (years)	Initial stocking (1)		Cut		Residual stand		Age (years)	Projected stand		
	Basal area	Volume	Basal area	Volume[1]	Basal area	Volume		Basal area[2]	Volume[3]	Total yield
	Sq ft	Cu ft	Sq ft	Cu ft	Sq ft	Cu ft		Sq ft	Cu ft	Cu ft
20	100.0	2,733	25.0	628	75	2,105	30	99.5	3,781	--
30	99.5	3,781	24.5	857	75	2,924	40	93	4,184	--
40	93	4,184	18	745	75	3,439	50	89	4,447	6,677

[1]Cut volume = square feet of basal area cut x cubic volume stocking/basal area stocking ratio x 0.92.
[2]Use equation (3).
[3]Use equation (1).

Table 4.--Projected board-foot yields for site 100 after thinning

Age (years)	Initial stand			Cut			Residual stand			Age (years)	Projected stand		
	Basal area	Volume		Basal area	Volume		Basal area	Volume			Basal area	Volume	
	Sq ft	Cu ft[1]	Bd ft[2]	Sq ft	Cu ft[1]	Bd ft[3]	Sq ft	Cu ft[1]	Bd ft[2]		Sq ft	Cu ft[1]	Bd ft[3]
20	75	2,111	2,718	25	647	0	50	1,464	2,636	30	76	2,967	8,789
30	76	2,967	8,789	26	934	1,991	50	2,033	6,798	40	68	3,185	11,872
40	68	3,185	11,872	18	776	2,324	50	2,409	9,548	50	64	3,324	13,634

[1]Includes cubic volume of all trees to a 4-inch top diameter outside bark.
[2]Use equation (4).
[3]Initial yield minus residual yield.

The cubic volume cut is again estimated using 92 percent of the cubic feet per square foot of basal area stocking ratio for the entire stand. After establishing the residual cubic volume in the prescribed manner, the residual board-foot estimate is obtained by entering equation (4) with the residual stand statistics. This is permissible because equation (4) was derived from data collected in thinned stands. It should also be understood that the initial cubic-volume stocking and projected yield include the cubic volume contained in the board-foot volume. These stocking data are included because they are

used in the board-foot estimating equation (4). Since the board-foot estimates represent solid wood, the cubic volume contained in the board-foot volumes can be obtained by dividing the latter values by 12. Subtracting the resulting figures from the total cubic-foot stocking values will produce estimates of the cubic volume not contained in the board-foot volumes (table 5).

The cubic volume estimates in table 5 include the saw kerf and slab and edging volumes involved in producing the board-foot volumes. An estimate of the slab and kerf volumes contained in the nonsawtimber volumes would add materially to the utility of the predicted yields. For example, landowners having per acre estimates each of board feet, slabs (chips), kerf, and topwood plus nonsawtimber tree volumes could more accurately determine timber stand values. Timber buyers would benefit in a like manner. If an estimate of the length and scaling diameter of the average log is available, slab and kerf volumes can be estimated (table 6). Kerf and slab and edging rules for logs of varying length and diameter were recently published.[3]

Table 5.--Projected board-foot and cordwood yields for site 100 after thinning

Age (years)	Initial stand			Cut			Residual stand			Age (years)	Projected stand		
	Basal area	Volume		Basal area	Volume		Basal area	Volume			Basal area	Volume	
	Sq ft	Cu ft [1]	Bd ft	Sq ft	Cu ft [1]	Bd ft	Sq ft	Cu ft [1]	Bd ft		Sq ft	Cu ft [1]	Bd ft
20	75	1,885	2,718	25	640	82	50	1,244	2,636	30	76	2,235	8,789
30	76	2,235	8,789	26	768	1,991	50	1,467	6,798	40	68	2,196	11,872
40	68	2,196	11,872	18	582	2,324	50	1,613	9,548	50	64	2,188	13,634

[1] Cubic volume from nonsawtimber trees plus topwood volume from sawtimber trees plus slab and kerf volume residues from producing the board-foot volume.

Table 6.--Saw-log residue volumes as percentages of the board-foot volume expressed in cubic feet

Log diameter (inches)	Kerf volume	Slab and edging volume by log length (feet)			
		10	12	14	16
		Percent			
7	40[1]	98	96	92	91
8	37	76	78	75	74
9	35	67	66	63	63
10	34	57	57	55	55
11	33	50	50	49	48
12	32	45	45	44	43
13	31	40	40	39	39
14	31	37	37	36	36
15	31	34	34	33	33
16	30	31	31	30	30
20	29	24	24	23	23
30	28	15	15	15	15

[1] These percentages apply to all log lengths.

[3] Bennett, Frank A. and F. Thomas Lloyd. 1974. Volume of saw-log residues as calculated by log rule formulae. USDA For. Serv. Res. Pap. SE-118, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

DISCUSSION

The primary purpose of this paper is to illustrate how published yield and projection equations can be used to compare thinning regimes for natural slash pine stands. One schedule involving cubic volume only is detailed in table 7. As a reminder, the posted yields prior to cutting were developed from stands that had been thinned one or more times and thus represent production for managed stands. The cut volume is determined by the technique previously described. Under the two residual stocking levels--75 and 100 square feet of basal area--the total yield at age 50 is about 11 percent greater on all sites for the higher stocking level. However, practically all of this difference is generated in the first 30 years. Growth between ages 30 and 50 does not differ greatly for the two stocking levels. Mean periodic annual growth between ages 20 and 30 is greater than that for either the prior or subsequent period. In fact, growth drops rapidly after age 30, as is indicated by the growth percents in table 7.

When residual basal area stocking is the same on all sites, projected basal area stockings are also the same on all sites. The result reflects no apparent effect of site on basal area growth. Under the imposed stand conditions (the same basal area stocking on all sites) this is a true stand relationship, which is the result of a decreasing number of trees per acre as site increases (table 7). For example, site 60 requires 943 trees to produce 100 square feet of basal area at age 20, whereas site 100 requires only 317 trees. The following tabulation further illustrates the point:

Site index class (feet)	Trees per acre (number)	Basal area yield[1] age 20 (square feet)	Basal area yield[1] age 30 (square feet)	10-year basal area growth (square feet)
60	943	100.0	129.44	29.55
100	317	100.0	129.54	29.54

[1] Caculated from the following equation:

$$\text{Log}_{10} \text{ basal area yield} = 1.52417 - \frac{6.74476}{\text{age}} - \frac{32.227}{\text{site}} + 0.45395 \, (\text{Log}_{10} \text{ number trees per acre})$$

$$R^2 = 0.70$$

Table 7.--Slash pine cubic-foot growth and yield at different stocking levels

SITE 60

Trees	Age	Basal area	Volume	Cut: Basal area	Cut: Volume	Residual stand: Basal area	Residual stand: Volume	Projected yield: Age	Projected yield: Basal area	Projected yield: Volume	Growth: 10-year: Basal area	Growth: 10-year: Volume	Growth: Annual: Basal area	Growth: Annual: Volume	Growth percent	Total yield
No.	Years	Sq ft	Cu ft	Sq ft	Cu ft	Sq ft	Cu ft	Years	Sq ft	Cu ft	Sq ft	Cu ft	Sq ft	Cu ft		Cu ft
[illegible]	20	100	1,214	25	279[2]	75	935	30	99.5	1,680	24.5	745	2.45	74	7.9	
	30	99.5	1,680	24.5	380	75	1,300	40	93	1,859	18.0	559	1.8	56	4.3	
	40	93	1,859	18	331	75	1,528	50	89	1,975	14.0	447	1.4	45	2.9	2,965
[illegible]	[illegible]	125	1,483	25	[illegible]	100	1,210	30	121	1,995	21	785	2.10	78	6.4	
	30	121	1,995	21	319	100	1,676	40	115	2,256	15	580	1.5	58	3.5	
	[illegible]	115	2,256	15	271	100	1,985	50	112	2,428	12	443	1.2	44	2.2	3,291
SITE 70																
640	20	[illegible]	1,622	25	373	75	1,249	30	99.5	2,244	24.5	995	2.45	99	8.0	
	[illegible]	[illegible]	2,244	24.5	508	75	1,736	40	93	2,484	18	748	1.8	75	4.3	
	40	93	2,484	[illegible]	442	75	2,042	50	89	2,639	14	597	1.4	60	2.9	3,962
1,040	20	125	1,982	[illegible]	365	100	1,617	30	121	2,665	21	1,048	2.10	[illegible]	6.5	
	30	121	2,665	[illegible]	425	100	2,240	40	115	3,014	15	[illegible]	1.5	77	3.4	
	[illegible]	115	3,014	[illegible]	362	100	2,652	50	112	3,244	12	592	1.2	59	2.2	4,396
SITE 80																
477	20	[illegible]	2,016	25	465	75	1,551	30	99.5	2,789	24.5	1,238	2.45	124	8.3	
	30	99.5	2,789	24.5	632	[illegible]	2,157	40	93	3,086	18	929	1.80	93	4.3	
	40	[illegible]	3,086	18	550	[illegible]	2,536	50	[illegible]	3,278	14	742	1.40	74	3.1	4,925
780	20	125	2,463	[illegible]	453	100	2,010	30	121	3,313	21	1,303	2.10	130	6.5	
	30	121	3,313	[illegible]	529	100	2,784	40	115	3,745	15	961	1.50	96	3.4	
	40	115	3,745	15	449	100	3,296	50	112	4,032	12	736	1.20	71	2.2	5,463
SITE 90																
380	[illegible]	100	2,387	[illegible]	537	75	1,850	30	99.5	3,303	24.5	1,453	[illegible]	145	7.8	
	30	99.5	3,303	24.5	[illegible]	75	2,571	40	93	3,655	18	1,084	1.80	108	4.2	
	[illegible]	[illegible]	[illegible]	18	[illegible]	75	3,018	50	89	3,884	14	866	1.40	[illegible]	2.9	5,790
[illegible]	20	125	2,916	[illegible]	536	100	2,380	30	121	3,923	21	[illegible]	2.10	[illegible]	6.5	
	30	121	3,923	21	626	100	3,297	40	115	4,435	15	1,138	1.50	114	3.5	
	40	115	4,435	15	532	100	3,903	50	112	4,774	12	871	1.20	[illegible]	2.2	6,463
SITE 100																
317	20	100	2,733	25	528	75	2,105	30	99.5	3,781	24.5	1,676	2.45	168	8.0	
	30	99.5	3,781	24.5	857	75	2,924	40	[illegible]	4,184	18	1,260	1.8	126	4.3	
	40	[illegible]	4,184	18	745	[illegible]	3,439	50	89	4,446	14	1,007	1.4	101	2.9	6,676
518	20	125	3,338	25	614	100	2,724	30	121	4,491	21	1,767	2.10	178	6.5	
	30	121	4,491	21	717	100	3,774	40	115	5,077	15	1,303	1.50	130	3.4	
	[illegible]	115	[illegible]	[illegible]	[illegible]	[illegible]	4,468	50	112	5,466	12	998	1.20	[illegible]	2.2	7,406

[1]Based on the equation on page 7.
[2]Based on 92 percent of the cubic-foot/basal area ratio for the entire stand.

Basal area growth and yield is obviously a function of number of trees per acre, and holding basal area constant across site, as in table 7, results in a decrease in trees per acre as site increases and thus the same basal area growth on all sites, when mortality is not a factor. These relationships are fully discussed in another publication.[4]

A thinning regime involving estimates of sawtimber volumes shows that board-foot growth peaks between ages 30 and 40 on sites 70 and 80, and between ages 20 and 30 on sites 90 and 100 (table 8). This variation is very probably related to the time at which maximum in-growth occurs on each site. It is also interesting that board-foot growth and yield increase as stocking is increased. This pattern is opposite to that for young plantations. Plottings of the observed natural stand data show the trend developed in table 8 to be real. This reversal between young planted and older natural stands reflects

[4] Bennett, Frank A. 1975. Some intriguing slash pine growth and yield relationships. USDA For. Serv. Res. Pap. SE-133, 12 p. Southeast. For. Exp. Stn., Asheville, N.C.

the difference in the age at which density control is initiated. With density controlled at time of establishment, low-density plantings enjoy much greater diameter growth and consequently produce much greater sawtimber volumes by age 25 or 30 than do the higher density stands. On the other hand, the natural stand data from which the predicted and projected yields were developed came from stands that were 20 years of age and older before density control was applied. Consequently, in many of the denser stands a majority of the trees were sawtimber size when the first measurements were made, and in the more lightly stocked stands (based on number of trees per acre) all of the trees were sawtimber size. As basal area of these stands increased, board-foot volumes increased because sawtimber trees were involved. If density control is applied early in the life of natural stands (as a precommercial thinning, for example), the pattern of board-foot growth and yield in relation to stocking would, of course, be similar to that in plantations.

Net growth data were used in developing the yield projection technique, and projected yields in tables 7 and 8 therefore represent net volumes under the prevailing study conditions. Annual losses in number of trees per acre during the 5-year study period were:

Site index class	Number trees lost per acre annually
60	0
70	0.7
80	2.2
90	3.6
100	2.1

The smaller losses on sites 60 and 70 may be a reflection of the effect of more thinning on the better sites in order to bring the plots to assigned residual densities. More thinning offered a greater opportunity for Fomes annosus infections and insect infestations. For example, over half of the losses occurred on 7 percent of the plots, and 39 percent of the plots suffered no mortality. Also, in a regression analysis, the interaction of age and number of trees per acre accounted for only 20 percent of the variation in mortality. The greater losses on the better sites reduced, of course, the effect of site on growth and yield. In field application of the management technique, observed growth during the projection period may be more or less than the projected figures in table 8, depending upon whether mortality is more or less than that experienced during the study.

The total yield in table 8 is segregated into board feet, slabs and edging volume, saw kerf, and cordwood (nonsawtimber trees plus topwood from sawtimber trees). The kerf and slab and edging volume estimates were developed, as indicated, by assuming an average log size for each stand portrayed in table 8 and applying the appropriate percentage from table 6 to the board-foot yield. These estimates are not precise, but a fairly large error in the estimated log diameter does not greatly affect the estimated saw kerf volume,

especially for the larger log sizes (table 6). Although the error of the slab volume estimates may be fairly high, their inclusion seems justified. In the absence of diameter frequency distributions and taper curves this is the only approach to isolating the kerf and slab volumes. In field application of the illustrated management planning techniques, more accurate estimates of average log sizes would, of course, be available.

This paper is meant only to illustrate how published yield and projection equations can be used to compare thinning regimes for natural slash pine. The examples are not suggested as optimum management schedules, but are models for forest owners and managers to use in developing management programs based on their own product objectives and methods of operation.

Table 8.--Multiproduct yields in managed natural slash pine stands

Age (years)	Initial stocking				Cut				Residual stand			
	Basal area	All trees	Products		Basal area	All trees	Products		Basal area	All trees	Products	
			Sawtimber	Cordwood[2]			Sawtimber	Cordwood[2]			Sawtimber	Cordwood[2]
	Sq ft	Cu ft	Bd ft	Cu ft	Sq ft	Cu ft	Bd ft	Cu ft	Sq ft	Cu ft	Bd ft	Cu ft
SITE 70												
20	75	1,253	0	1,253	25	384	0	384	50	869	0	869
30	76	1,761	0	1,761	26	554	0	554	50	1,207	0	1,207
40	68	1,891	2,408	1,690	18	461	21	459	50	1,430	2,387	1,231
20	100	1,622	0	1,622	33	492	0	492	67	1,130	0	1,130
30	92	2,098	0	2,098	25	524	0	524	67	1,574	276	1,551
40	85	2,304	2,264	2,115	18	458	0	458	67	1,846	2,265	1,657
SITE 80												
20	75	1,558	0	1,558	25	478	0	478	50	1,080	0	1,080
30	76	2,189	1,862	2,034	26	689	199	672	50	1,500	1,662	1,361
40	68	2,350	5,765	1,870	18	572	832	503	50	1,778	4,933	1,367
20	100	2,016	0	2,016	33	612	0	612	67	1,404	0	1,404
30	92	2,607	3,177	2,342	25	652	115	642	67	1,955	3,062	1,700
40	85	2,861	6,338	2,333	18	557	723	497	67	2,304	5,615	1,836
SITE 90												
20	75	1,844	764	700	25	565	0	565	50	1,279	764	1,215
30	76	2,594	6,046	2,088	26	816	1,128	722	50	1,778	4,918	1,366
40	68	2,782	8,925	2,038	18	678	1,608	544	50	2,104	7,317	1,494
20	100	2,387	81	2,380	33	725	0	725	67	1,662	81	1,655
30	92	3,087	6,688	2,530	25	771	985	689	67	2,316	5,703	1,841
40	85	3,388	10,192	2,539	18	660	1,476	537	67	2,728	8,716	2,002
SITE 100												
20	75	2,111	2,718	1,885	25	647	0	647	50	1,464	2,718	1,238
30	76	2,967	8,789	2,235	26	934	1,991	768	50	2,033	6,798	1,467
40	68	3,185	11,872	2,196	18	776	2,324	582	50	2,409	9,548	1,613
20	100	2,733	2,609	2,516	33	840	0	840	67	1,893	2,609	1,676
30	92	3,534	9,957	2,704	25	893	1,877	737	67	2,641	8,080	1,968
40	85	3,878	13,776	2,730	18	764	2,237	578	67	3,114	11,539	2,152

[1] Site 60 does not produce enough sawtimber to warrant inclusion.

[2] Contains slab and kerf volumes required to produce the board foot yield, if any.

Table 8.--Multiproduct yields in managed natural slash pine stands (continued)

Age (years)	Projected stand				Periodic annual growth				Total yield					Estimated average log diameter[5]
	Basal area	All trees	Products		Basal area	All trees	Products		All trees	Sawtimber	Products			
			Sawtimber	Cordwood[3]			Sawtimber	Cordwood[3]			Slab and edging[3]	Kerf[3]	Cordwood[4]	
	Sq ft	Cu ft	Bd ft	Cu ft	Sq ft	Cu ft	Bd ft	Cu ft	Cu ft	Bd ft	Cu ft	Cu ft	Cu ft	Inches
SITE 70[1]														
30	76	1,761	0	1,761	2.6	89	0	89						
40	68	1,891	2,408	1,690	1.8	68	241	48						
50	64	1,973	3,753	1,660	1.4	54	137	43	3,372	3,774	236	116	2,706	8
30	92	2,098	0	2,098	2.5	97	0	97						
40	85	2,304	2,264	2,115	1.8	73	199	56						
50	81	2,434	3,960	2,104	1.4	59	169	45	3,908	3,960	304	132	3,142	7
SITE 80														
30	76	2,189	1,862	2,034	2.6	111	203	94						
40	68	2,350	5,765	1,870	1.8	85	410	51						
50	64	2,452	7,256	1,847	1.4	67	232	48	4,191	8,287	435	242	2,823	9
30	92	2,607	3,177	2,342	2.5	120	234	101						
40	85	2,861	6,338	2,333	1.8	91	328	63						
50	81	3,025	8,282	2,335	1.4	72	267	50	4,846	9,120	570	281	3,235	8
SITE 90														
30	76	2,592	6,046	2,088	2.6	131	528	87						
40	68	2,782	8,925	2,038	1.8	101	401	67						
50	64	2,904	10,562	2,024	1.4	80	324	53	4,963	13,298	609	377	2,869	10
30	92	3,087	6,688	2,530	2.5	142	661	87						
40	85	3,388	10,192	2,539	1.8	107	449	70						
50	81	3,582	12,356	2,552	1.4	85	364	55	5,738	14,817	778	432	3,293	9
SITE 100														
30	76	2,967	8,789	2,235	2.6	150	533	106						
40	68	3,185	11,872	2,196	1.8	115	507	73						
50	64	3,324	13,634	2,188	1.4	100	409	57	5,681	17,286	706	475	3,060	11
30	92	3,534	9,957	2,704	2.5	164	735	103						
40	85	3,878	13,776	2,730	1.8	124	570	76						
50	81	4,101	16,152	2,755	1.4	99	461	60	6,598	20,266	929	574	3,406	10

[3]Bennett, Frank A., and F. Thomas Lloyd. 1974. Volume of saw-log residues as calculated from log rule formulae. USDA For. Serv. Res. Pap. SE-118, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

[4]Includes nonsawtimber trees and topwood from sawtimber trees.

[5]Estimated average log length = 14 feet.

Bennett, Frank A.
1975. A technique for comparing thinning schedules for natural slash pine stands. USDA For. Serv. Res. Pap. SE-138, 11 p. Southeast. For. Exp. Stn., Asheville, N.C.

This paper illustrates how previously published yield and projection equations can be used to devise a technique for comparing thinning levels in natural slash pine stands. Total yield at rotation end is presented for all trees as pulpwood, and as multiple products--board feet, slabs and edgings, kerf, and cordwood.

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DA Forest Service Research Paper SE-139 November 1975

tem and Primary Product Weights for Longleaf Pine Sawtimber Trees

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Stem and Primary Product Weights for Longleaf Pine Sawtimber Trees

by

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Most appraisals of standing timber are based on estimates taken from volume tables and applied to the timber cruised. Volume tables apparently provide adequate estimates of lumber volumes, but they ignore other primary products generated during sawmilling. A volume table does not show the amount of bark, sawdust, and chippable residue from slabs, edgings, and end trim that will be produced from a tree of a given size. These primary products are important to the sawmilling industry and to people concerned with determining current timber volumes and production.

Since weight-scaling is the accepted method of buying and selling pine logs in the South, it appears that tables based on weight should also be an acceptable means of estimating the proportion of lumber and other primary products in pine sawtimber trees. The study described here was conducted to determine stem and primary product weights for longleaf pine (Pinus palustris Mill.) sawtimber trees and to develop predicting equations to estimate these weights when the logs from the trees are processed at a sawmill.

This study was conducted by the Southeastern Forest Experiment Station in cooperation with and through the financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System. Field personnel were provided by the Conecuh District of the Conecuh National Forest. Cooperation and assistance were also received from the Windham Lumber Company.

PROCEDURE

Field

Forty-eight longleaf pine sawtimber trees were selected from a natural stand on the Conecuh National Forest in southern Alabama. Trees were selected to represent the range in timber size on the Forest; average tree characteristics are listed below.

Item	Average	Range
D.b.h. (inches)	14.4	9.8 - 19.4
Total height (feet)	83	59 - 97
Merchantable height (feet)	54	34 - 73
Form class	83	75 - 92
Age (years, at d.b.h.)	48	30 - 60

Sample trees were felled and bucked into saw logs to an approximate minimum top diameter (merchantable top) of 6 inches inside bark. Upper log merchantability was stopped at a point where the diameter exceeded 6 inches when stem branchiness prevented utilization to the lower diameter; the average top diameter in this study was 7.2 inches. Pulpwood above the merchantable saw-log top was cut to 4- and 2-inch top diameters. The pulpwood was weighed in the woods to the nearest pound on a portable scale.

Saw logs were weighed individually in the millyard before and after debarking; bark weight of each log was computed by subtraction and totaled for each tree.

Moisture content and specific gravity of wood and bark were determined from cross-section disks taken at each bucking point along the stem. Moisture content samples were dried at 103° C until a constant weight was reached. Moisture content is expressed on an ovendry basis; specific gravity is expressed on a green volume-ovendry weight basis. Stemwood cubic-foot volumes were determined by applying Smalian's formula to individual log measurements and summing these values for individual trees.

Sawmill

Debarked logs were sawed into 4/4 and 8/4 lumber on a circular headsaw which had a 5/16-inch kerf. As the logs were sawed, the chippable residues (slabs, edgings, and end trim) were collected and weighed. The lumber from each log was also tallied by weight and volume. A 6-foot 1 by 4 was the smallest board retained by the mill.

Analysis

Regression equations were developed to estimate stem weight with and without bark and cubic volume to a 6-, 4-, and 2-inch top. Additional equations estimate lumber volume and the weight of lumber, chippable residue, bark, and sawdust produced during sawing.

All equations are of the form:

$$Y = b_0 + b_1 D^2Mh + e$$

where:

Y = weight or volume of the tree component

b_0, b_1 = regression coefficients

D = tree diameter at breast height in inches

Mh = tree height to the merchantable top in feet

e = experimental error.

Grouping of the data into D^2Mh classes indicated that the variance of the dependent variable was homogeneous and did not increase with increasing tree size. Since the basic assumptions of regression analysis were met, the unweighted linear model was used to predict weights and volumes of the tree components.

RESULTS AND DISCUSSION

General

The saw-log portions of the 48 trees weighed a total of 120,413 pounds and yielded an average of 9 percent bark residue, 16 percent sawdust, 54 percent lumber, and 21 percent chippable residue (table 1).

The percentage of merchantable stem weight in sawdust was essentially constant at 16 percent across the range of tree sizes sampled. Bark percentage also varied little with tree size, ranging from 8 to 10 percent and averaging 9 percent of stem weight.

Lumber recovery factor, the ratio of lumber produced per cubic foot of saw-log material, averaged 6.48 board feet per cubic foot and increased from a low of 5.80 for 10-inch trees to a high of 6.84 for 18-inch trees.

Table 1.--Average size, weight, volume, and proportion of primary product recovery for longleaf pine sawtimber trees

D.b.h. class (inches)	Merchantable height[1]	Merchantable stem weight[2]	Primary product recovery				Lumber tally	Volume merchantable stem[3]	Lumber recovery factor	Sample size
			Lumber	Chippable residue	Sawdust	Bark residue				
	Feet	Pounds	- - - - - - - - - Percent - - - - - - - - -				Board feet	Cubic feet	Board feet/ cubic feet	Number
10	40	968	48	26	17	9	80	13.8	5.80	8
12	55	1,721	51	23	17	9	156	25.6	6.09	8
14	56	2,277	52	22	17	9	210	33.4	6.29	8
15	66	2,994	57	17	17	9	308	46.0	6.70	1
16	60	3,155	54	22	16	8	312	47.9	6.51	11
17	53	3,272	56	19	16	9	336	49.3	6.82	8
18	54	3,584	55	21	16	8	364	53.2	6.84	2
19	70	4,822	52	22	16	10	471	71.0	6.63	2
Study average		2,509	54	21	16	9	243	37.5	6.48	--

[1] Merchantable height to 6-inch or merchantable top includes 1-foot stump allowance.
[2] Weight of saw-log portion of stem with bark.
[3] Stemwood volume, inside bark.

Physical Properties of Wood and Bark

The moisture content, specific gravity, and green weight per cubic foot of wood and bark are shown in the following tabulation. Since specific gravity, moisture content, and weight per cubic foot of wood and bark did not vary with tree size, only the study averages and standard deviations are shown.

Type of material	Moisture content (percent)	Specific gravity	Weight/ cubic foot (pounds)
Wood			
Saw-log portion	79.4 ± 8.8	0.559 ± 0.034	62.4 ± 2.1
Pulpwood portion	108.1 ± 16.0	0.501 ± 0.041	64.8 ± 2.5
Bark			
Saw-log portion	57.3 ± 7.7	0.408 ± 0.027	40.0 ± 2.7
Pulpwood portion	84.1 ± 13.2	0.391 ± 0.030	44.8 ± 3.5

The moisture contents of both wood and bark were higher in the pulpwood portion of the tree than in the saw-log portion, while the specific gravities of both wood and bark were lower in the pulpwood portion of the tree. Green weight per cubic foot of wood and bark was higher in the pulpwood section because the moisture content in this section of the tree was higher.

Prediction Equations and Yield Tables

Regression equations to predict weight or volume of the merchantable stem and the primary products are shown in table 2. All equations had coefficients of determination of 0.90 or larger; coefficients of variation ranged from 7.3 to 12.5 percent. The equations in table 2 were used to generate tables of stem weights and volumes and the weight of primary products produced in sawmilling.

Appendix tables show estimates of weight or volume of the main stem of longleaf pine trees and the weight or volume of lumber, bark, sawdust, and chippable residue produced when the logs from the trees are sawed.

Table 2.--Regression equations and associated statistics to predict longleaf pine stem weights, volumes, and primary product yields

Dependent variable and unit of measure	Equation	Coefficient of determination ($\underline{R}^3$)	Standard error of estimate ($S_{y \cdot x}$)	Coefficient of variation (CV)
Stem weight with bark (pounds)				
Saw-log top	$Y = 258.37218 + 0.18648\ D^2Mh$	0.97	182.0	7.3
4-inch top	$Y = 455.33218 + 0.18695\ D^2Mh$	0.92	307.0	11.3
2-inch top	$Y = 486.69792 + 0.18651\ D^2Mh$	0.92	308.1	11.3
Stem weight without bark (pounds)				
Saw-log top	$Y = 231.89438 + 0.17036\ D^2Mh$	0.97	177.2	7.7
4-inch top	$Y = 411.04012 + 0.17073\ D^2Mh$	0.92	287.5	11.6
2-inch top	$Y = 439.86186 + 0.17032\ D^2Mh$	0.91	288.6	11.6
Stem bark weight (pounds)				
4-inch top	$Y = 44.29207 + 0.01622\ D^2Mh$	0.90	30.0	12.5
2-inch top	$Y = 46.83605 + 0.01619\ D^2Mh$	0.90	30.1	12.4
Stem wood volume (cubic feet)				
Saw-log top	$Y = 3.17916 + 0.00284\ D^2Mh$	0.97	2.9	7.8
4-inch top	$Y = 6.00302 + 0.00286\ D^2Mh$	0.91	4.9	12.1
2-inch top	$Y = 6.43921 + 0.00285\ D^2Mh$	0.91	4.9	12.0
Primary product weight (pounds)				
Bark residue	$Y = 26.47780 + 0.01613\ D^2Mh$	0.95	20.8	9.4
Sawdust	$Y = 54.98038 + 0.02950\ D^2Mh$	0.96	33.5	8.2
Lumber	$Y = 74.81510 + 0.10473\ D^2Mh$	0.94	146.6	11.0
Chippable residue	$Y = 102.09890 + 0.03613\ D^2Mh$	0.91	62.9	11.7
Lumber volume (board feet)	$Y = 3.74017 + 0.01983\ D^2Mh$	0.95	25.7	10.6

Appendix tables 3-6 give predicted green weights of chippable residue, bark residue, sawdust, and lumber, respectively. The predicted lumber volume in board feet is presented in Appendix table 7 for trees 10-22 inches d.b.h.

Appendix tables 8-15 present stem weights with and without bark and bark weight for longleaf pine trees utilized to a saw-log top, a 4-inch top, or a 2-inch top. Appendix tables 16-18 present the cubic-foot wood volume in the stems of the trees utilized to the three different top diameters.

The use of these tables should be limited to stands where the physical properties of the trees are similar to those reported in this paper. Primary product yields are strongly influenced by the type of equipment used to process the logs and by processing techniques. Thus, it is unlikely that our predictions of the amount of primary products recoverable from longleaf pine trees apply where processing techniques differ considerably from those of the study.

Appendix

Table 3.--Predicted[1] weight of chippable residue from the saw-log portion of longleaf pine trees[2]

D.b.h. class (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	164	192	221	250	279	308			
11	176	211	246	281	316	351	386		
12	191	232	274	315	357	399	440	482	
13	206	255	304	352	401	450	499	548	
14	222	279	336	392	449	506	562	619	676
15	240	305	370	435	500	565	631	696	761
16	259	333	407	481	555	629	703	777	851
17		363	447	530	614	697	781	864	948
18		395	488	582	676	769	863	957	1,050
19		428	533	637	741	846	950	1,054	1,159
20		463	579	695	810	926	1,041	1,157	1,273
21			628	755	883	1,010	1,138	1,265	1,393
22			679	819	959	1,099	1,239	1,379	1,519

[1] Based on the equation $\hat{Y} = 102.09890 + 0.03613\ D^2Mh$.
[2] Blocked-in areas indicate range of our data.
[3] Includes 1-foot stump allowance.

Table 4.--Predicted[1] bark weight from the saw-log portion of longleaf pine trees[2]

D.b.h. class (inches)	Merchantable height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	54	67	80	93	106	118			
11	60	75	91	106	122	138	153		
12	66	85	103	122	140	159	177	196	
13	73	95	116	138	160	182	204	225	
14	80	106	131	156	181	207	232	257	283
15	88	117	146	175	204	233	262	291	320
16	97	130	163	196	229	262	295	328	361
17		143	180	218	255	292	329	367	404
18		157	199	241	283	324	366	408	450
19		172	219	265	312	358	405	452	498
20		188	239	291	343	394	446	497	549
21			261	318	375	432	489	546	603
22			284	347	409	471	534	596	659

[1] Based on the equation $\hat{Y} = 26.47780 + 0.01613\ D^2Mh$.
[2] Blocked-in areas indicate range of our data.
[3] Includes 1-foot stump allowance.

Table 5.--Predicted[1] weight of sawdust from the saw-log portion of longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	105	129	152	176	200	223			
11	116	144	173	201	230	258	287		
12	127	161	195	229	263	297	331	365	
13	140	180	220	259	299	339	379	419	
14	153	200	246	292	338	385	431	477	523
15	168	221	274	327	380	433	486	540	593
16	183	244	304	365	425	485	546	606	667
17		268	336	405	473	541	609	677	746
18		294	370	447	523	600	676	753	829
19		321	406	492	577	662	747	832	918
20		350	444	539	633	728	822	916	1,011
21			484	588	692	797	901	1,005	1,109
22			526	640	755	869	983	1,097	1,211

[1]Based on the equation $\hat{Y} = 54.98038 + 0.02950\ D^2Mh$.
[2]Blocked-in areas indicate range of our data.
[3]Includes 1-foot stump allowance.

Table 6.--Predicted[1] weight of lumber from the saw-log portion of longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	253	337	420	504	588	672			
11	290	392	493	594	696	797	899		
12	331	452	572	693	814	934	1,055	1,176	
13	376	517	659	800	942	1,084	1,225	1,367	
14	424	588	752	916	1,081	1,245	1,409	1,573	1,738
15	475	664	852	1,041	1,229	1,418	1,606	1,795	1,984
16	531	745	960	1,174	1,389	1,603	1,818	2,032	2,246
17		831	1,074	1,316	1,558	1,800	2,042	2,284	2,526
18		923	1,195	1,466	1,738	2,009	2,280	2,552	2,823
19		1,020	1,322	1,625	1,927	2,230	2,532	2,835	3,137
20		1,122	1,457	1,792	2,128	2,463	2,798	3,133	3,468
21			1,599	1,968	2,338	2,707	3,077	3,446	3,816
22			1,748	2,153	2,559	2,964	3,370	3,775	4,181

[1]Based on the equation $\hat{Y} = 74.81510 + 0.10473\ D^2Mh$.
[2]Blocked-in areas indicate range of our data.
[3]Includes 1-foot stump allowance.

Table 7.--Predicted[1] lumber volume from the saw-log portion of longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Board feet								
10	37	53	69	85	101	117			
11	45	64	83	102	121	141	160		
12	52	75	98	121	144	167	189	212	
13	61	88	114	141	168	195	222	248	
14	70	101	132	163	194	225	256	287	319
15	80	115	151	187	222	258	294	329	365
16	90	131	171	212	252	293	334	374	415
17		147	193	239	285	330	376	422	468
18		164	216	267	319	370	421	473	524
19		183	240	297	355	412	469	526	584
20		202	265	329	392	456	519	583	646
21			292	362	432	502	572	642	712
22			320	397	474	551	628	704	781

[1]Based on the equation $\hat{Y} = 3.74017 + 0.01983\ D^2Mh$.
[2]Blocked-in areas indicate range of our data.
[3]Includes 1-foot stump allowance.

Table 8.--Predicted[1] stem weight with bark to merchantable saw-log top for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	575	725	874	1,023	1,172	1,321			
11	642	822	1,003	1,183	1,364	1,545	1,725		
12	715	930	1,145	1,359	1,574	1,789	2,004	2,219	
13	794	1,046	1,298	1,550	1,803	2,055	2,307	2,559	
14	880	1,172	1,465	1,757	2,049	2,342	2,634	2,927	3,219
15	972	1,307	1,643	1,979	2,314	2,650	2,986	3,321	3,657
16	1,070	1,452	1,834	2,216	2,598	2,979	3,361	3,743	4,125
17		1,606	2,037	2,468	2,899	3,330	3,761	4,193	4,624
18		1,769	2,252	2,736	3,219	3,702	4,186	4,669	5,152
19		1,941	2,480	3,018	3,557	4,096	4,634	5,173	5,711
20		2,123	2,720	3,317	3,913	4,510	5,107	5,704	6,300
21			2,972	3,630	4,288	4,946	5,604	6,262	6,920
22			3,237	3,959	4,681	5,403	6,125	6,847	7,569

[1]Based on the equation $\hat{Y} = 258.37218 + 0.18648\ D^2Mh$.
[2]Blocked-in areas indicate range of our data.
[3]Includes 1-foot stump allowance.

Table 9.--Predicted[1] stem weight without bark to merchantable saw-log top for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	522	658	794	930	1,067	1,203			
11	582	747	912	1,077	1,242	1,407	1,572		
12	649	845	1,041	1,238	1,434	1,630	1,826	2,023	
13	721	952	1,182	1,412	1,643	1,873	2,103	2,334	
14	800	1,067	1,334	1,601	1,868	2,135	2,402	2,669	2,937
15	884	1,190	1,497	1,803	2,110	2,417	2,723	3,030	3,337
16	973	1,322	1,671	2,020	2,369	2,718	3,067	3,416	3,764
17		1,463	1,857	2,250	2,644	3,038	3,432	3,826	4,220
18		1,612	2,053	2,495	2,937	3,378	3,820	4,261	4,703
19		1,769	2,261	2,753	3,245	3,737	4,229	4,721	5,213
20		1,935	2,481	3,026	3,571	4,116	4,661	5,206	5,752
21			2,711	3,312	3,913	4,514	5,115	5,716	6,317
22			2,953	3,613	4,272	4,932	5,591	6,251	6,911

[1]Based on the equation $\hat{Y} = 231.89438 + 0.17036\ D^2Mh$.
[2]Blocked-in areas indicate range of our data.
[3]Includes 1-foot stump allowance.

Table 10.--Predicted[1] stem weight with bark to a 4-inch top diameter for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	773	923	1,072	1,222	1,371	1,521			
11	840	1,021	1,202	1,383	1,564	1,745	1,926		
12	913	1,128	1,344	1,559	1,774	1,990	2,205	2,421	
13	992	1,245	1,498	1,751	2,003	2,256	2,509	2,762	
14	1,078	1,371	1,665	1,958	2,251	2,544	2,837	3,130	3,423
15	1,170	1,507	1,843	2,180	2,516	2,853	3,189	3,526	3,862
16	1,269	1,652	2,035	2,418	2,800	3,183	3,566	3,949	4,332
17		1,806	2,238	2,671	3,103	3,535	3,967	4,399	4,832
18		1,970	2,454	2,939	3,423	3,908	4,392	4,877	5,362
19		2,143	2,682	3,222	3,762	4,302	4,842	5,382	5,922
20		2,325	2,923	3,521	4,120	4,718	5,316	5,914	6,513
21			3,176	3,836	4,495	5,155	5,814	6,474	7,133
22			3,441	4,165	4,889	5,613	6,337	7,061	7,785

[1]Based on the equation $\hat{Y} = 455.33218 + 0.18695\ D^2Mh$.
[2]Blocked-in areas indicate range of our data.
[3]Includes 1-foot stump allowance.

Table 11.--Predicted[1] stem weight without bark to a 4-inch top diameter for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	701	838	974	1,111	1,248	1,384			
11	762	927	1,093	1,258	1,423	1,589	1,754		
12	829	1,026	1,222	1,419	1,616	1,812	2,009	2,206	
13	902	1,132	1,363	1,594	1,825	2,056	2,287	2,517	
14	980	1,248	1,515	1,783	2,051	2,318	2,586	2,854	3,122
15	1,064	1,371	1,679	1,986	2,293	2,601	2,908	3,215	3,523
16	1,154	1,504	1,853	2,203	2,553	2,902	3,252	3,602	3,951
17		1,645	2,039	2,434	2,829	3,223	3,618	4,013	4,408
18		1,794	2,236	2,679	3,122	3,564	4,007	4,449	4,892
19		1,952	2,445	2,938	3,431	3,924	4,417	4,910	5,403
20		2,118	2,665	3,211	3,757	4,304	4,850	5,396	5,943
21			2,896	3,498	4,100	4,703	5,305	5,907	6,510
22			3,138	3,799	4,460	5,121	5,782	6,443	7,104

[1] Based on the equation $\hat{Y} = 411.04012 + 0.17073\ D^2Mh$.
[2] Blocked-in areas indicate range of our data.
[3] Includes 1-foot stump allowance.

Table 12.--Predicted[1] weight of bark to a 4-inch top diameter for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	72	85	98	111	124	137			
11	78	93	109	125	140	156	172		
12	84	103	121	140	159	177	196	215	
13	91	113	135	157	179	201	222	244	
14	98	124	149	175	200	226	251	276	302
15	106	136	165	194	223	252	282	311	340
16	115	148	181	215	248	281	314	347	381
17		161	199	236	274	311	349	386	424
18		176	218	260	302	344	386	428	470
19		191	238	284	331	378	425	472	519
20		206	258	310	362	414	466	518	570
21			280	338	395	452	509	566	624
22			303	366	429	492	555	617	680

[1] Based on the equation $\hat{Y} = 44.29207 + 0.01622\ D^2Mh$.
[2] Blocked-in areas indicate range of our data.
[3] Includes 1-foot stump allowance.

Table 13.--Predicted[1] stem weight with bark to a 2-inch top diameter for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	804	953	1,102	1,251	1,401	1,550			
11	870	1,051	1,231	1,412	1,593	1,773	1,954		
12	943	1,158	1,373	1,588	1,803	2,018	2,232	2,447	
13	1,023	1,275	1,527	1,779	2,031	2,283	2,536	2,788	
14	1,108	1,401	1,693	1,985	2,278	2,570	2,863	3,155	3,448
15	1,200	1,536	1,872	2,207	2,543	2,879	3,214	3,550	3,886
16	1,298	1,680	2,062	2,444	2,826	3,208	3,590	3,972	4,354
17		1,834	2,265	2,697	3,128	3,559	3,990	4,421	4,853
18		1,997	2,481	2,964	3,448	3,931	4,415	4,898	5,381
19		2,170	2,709	3,247	3,786	4,325	4,863	5,402	5,940
20		2,352	2,949	3,545	4,142	4,739	5,336	5,933	6,530
21			3,201	3,859	4,517	5,175	5,833	6,491	7,149
22			3,466	4,188	4,910	5,632	6,354	7,076	7,799

[1]Based on the equation $\hat{Y} = 486.69792 + 0.18651\ D^2Mh$.
[2]Blocked-in areas indicate ranges of our data.
[3]Includes 1-foot stump allowance.

Table 14.--Predicted[1] stem weight without bark to a 2-inch top diameter for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	729	866	1,002	1,138	1,274	1,411			
11	790	955	1,120	1,285	1,450	1,615	1,779		
12	857	1,053	1,249	1,445	1,642	1,838	2,034	2,230	
13	929	1,159	1,390	1,620	1,850	2,081	2,311	2,541	
14	1,007	1,274	1,541	1,809	2,076	2,343	2,610	2,877	3,144
15	1,091	1,398	1,704	2,011	2,318	2,624	2,931	3,237	3,544
16	1,181	1,530	1,879	2,228	2,576	2,925	3,274	3,623	3,972
17		1,670	2,064	2,458	2,852	3,246	3,639	4,033	4,427
18		1,819	2,261	2,702	3,144	3,585	4,027	4,468	4,910
19		1,977	2,469	2,961	3,453	3,945	4,436	4,928	5,420
20		2,143	2,688	3,233	3,778	4,323	4,868	5,413	5,958
21			2,919	3,519	4,120	4,721	5,322	5,923	6,524
22			3,160	3,820	4,479	5,139	5,798	6,458	7,117

[1]Based on the equation $\hat{Y} = 439.86186 + 0.17032\ D^2Mh$.
[2]Blocked-in areas indicate ranges of our data.
[3]Includes 1-foot stump allowance.

Table 15. --Predicted[1] weight of bark to a 2-inch top diameter for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Pounds								
10	74	87	100	113	126	139			
11	80	96	111	127	143	158	174		
12	86	105	124	142	161	180	198	217	
13	93	115	137	159	181	203	225	247	
14	101	126	152	177	202	228	253	278	304
15	109	138	167	196	225	254	284	313	342
16	117	150	184	217	250	283	316	349	383
17		164	201	239	276	314	351	388	426
18		178	220	262	304	346	388	430	472
19		193	240	286	333	380	427	473	520
20		209	261	312	364	416	468	520	571
21			282	340	397	454	511	568	625
22			305	368	431	493	556	619	682

[1] Based on the equation $\hat{Y} = 46.83605 + 0.01619\ D^2Mh$.
[2] Blocked-in areas indicate range of our data.
[3] Includes 1-foot stump allowance.

Table 16. --Predicted[1] cubic volume of wood in the merchantable saw-log stem of longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Cubic feet								
10	8.0	10.3	12.6	14.8	17.1	19.4			
11	9.0	11.8	14.5	17.3	20.0	22.8	25.5		
12	10.1	13.4	16.7	19.9	23.2	26.5	29.8	33.0	
13	11.3	15.2	19.0	22.9	26.7	30.5	34.4	38.2	
14	12.6	17.1	21.5	26.0	30.5	34.9	39.4	43.8	48.3
15	14.0	19.2	24.3	29.4	34.5	39.6	44.7	49.8	54.9
16	15.5	21.4	27.2	33.0	38.8	44.6	50.4	56.3	62.1
17		23.7	30.3	36.8	43.4	50.0	56.5	63.1	69.7
18		26.2	33.5	40.9	48.3	55.6	63.0	70.4	77.7
19		28.8	37.0	45.2	53.4	61.6	69.8	78.0	86.2
20		31.6	40.7	49.8	58.8	67.9	77.0	86.1	95.2
21			44.5	54.5	64.5	74.6	84.6	94.6	104.6
22			48.5	59.5	70.5	81.5	92.5	103.5	114.5

[1] Based on the equation $\hat{Y} = 3.17916 + 0.00284\ D^2Mh$.
[2] Blocked-in areas indicate range of our data.
[3] Includes 1-foot stump allowance.

Table 17.--Predicted[1] cubic volume of wood to a 4-inch top for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Cubic feet								
10	10.9	13.2	15.4	17.7	20.0	22.3			
11	11.9	14.7	17.4	20.2	23.0	25.7	28.5		
12	13.0	16.3	19.6	22.9	26.2	29.5	32.8	36.1	
13	14.2	18.1	22.0	25.8	29.7	33.6	37.4	41.3	
14	15.5	20.0	24.5	29.0	33.5	38.0	42.4	46.9	51.4
15	16.9	22.1	27.2	32.4	37.5	42.7	47.8	53.0	58.1
16	18.4	24.3	30.2	36.0	41.9	47.7	53.6	59.5	65.3
17		26.7	33.3	39.9	46.5	53.1	59.7	66.3	73.0
18		29.2	36.6	44.0	51.4	58.8	66.2	73.6	81.1
19		31.8	40.1	48.3	56.6	64.9	73.1	81.4	89.6
20		34.6	43.8	52.9	62.1	71.2	80.4	89.5	98.7
21			47.6	57.7	67.8	77.9	88.0	98.1	108.2
22			51.7	62.8	73.8	84.9	96.0	107.1	118.1

[1] Based on the equation $\hat{Y} = 6.00302 + 0.00286\ D^2Mh$.
[2] Blocked-in areas indicate range of our data.
[3] Includes 1-foot stump allowance.

Table 18.--Predicted[1] cubic volume of wood to a 2-inch top for longleaf pine trees[2]

D.b.h. class (inches)	Merchantable tree height (number of 16-foot logs)[3]								
	1	1-1/2	2	2-1/2	3	3-1/2	4	4-1/2	5
	Cubic feet								
10	11.3	13.6	15.8	18.1	20.4	22.7			
11	12.3	15.1	17.8	20.6	23.3	26.1	28.9		
12	13.4	16.7	20.0	23.3	26.5	29.8	33.1	36.4	
13	14.6	18.5	22.3	26.2	30.0	33.9	37.7	41.6	
14	15.9	20.4	24.9	29.3	33.8	38.3	42.7	47.2	51.7
15	17.3	22.5	27.6	32.7	37.9	43.0	48.1	53.3	58.4
16	18.8	24.7	30.5	36.4	42.2	48.0	53.9	59.7	65.5
17		27.0	33.6	40.2	46.8	53.4	60.0	66.6	73.2
18		29.5	36.9	44.3	51.7	59.1	66.5	73.8	81.2
19		32.2	40.4	48.6	56.9	65.1	73.3	81.5	89.8
20		34.9	44.1	53.2	62.3	71.4	80.5	89.7	98.8
21			47.9	58.0	68.0	78.1	88.1	98.2	108.2
22			52.0	63.0	74.0	85.1	96.1	107.1	118.2

[1] Based on the equation $\hat{Y} = 6.43921 + 0.00285\ D^2Mh$.
[2] Blocked-in areas indicate range of our data.
[3] Includes 1-foot stump allowance.

Schroeder, James G., Michael A. Taras, and Alexander Clark III

1975. Stem and primary product weights for longleaf pine sawtimber trees. USDA For. Serv. Res. Pap. SE-139, 15 p. Southeast. For. Exp. Stn., Asheville, N.C.

Forty-eight longleaf pine (Pinus palustris Mill.) sawtimber trees 10 to 19 inches d.b.h. were processed into lumber on a circular sawmill in south Alabama. Stem and product weights and volumes were determined and regression equations developed to predict stem weight, volume, and the weight of bark, sawdust, lumber, and chippable residue produced in the sawmill. Tables showing estimates of these weights and volumes are provided for trees 10 to 22 inches d.b.h.

The sawing portions of the trees yielded an average of 7 percent bark, 16 percent sawdust, 23 percent chippable residue, and 54 percent lumber by weight.

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SDA Forest Service Research Paper SE-140 October 1975

Fifteenth-Year Results from Progeny Tests of Slash Pine

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by

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Southeastern Forest Experiment Station
Asheville, North Carolina

Fifteenth-Year Results from Progeny Tests of Slash Pine

by

Earl R. Sluder, Plant Geneticist
Macon, Georgia

When tree breeding work at Macon, Georgia, began in the early 1950's, little was known about inheritance in the southern pines. The first phase of the work, therefore, was to select a number of phenotypically superior trees and a few phenotypically inferior trees of the southern pine species and to progeny test them to study inheritance and possibly to accumulate some superior genotypes in a clone bank for further breeding. This report presents 15th-year results from progeny tests of 49 slash pines (Pinus elliottii Engelm.).

MATERIALS AND METHODS

Forty-three slash pine trees were selected in plantations of unknown provenance in Clarke (C), Dooly (D), and Jones (J) Counties, Georgia. Three trees were selected in natural stands in Georgia, one in Bleckley (B) and two in Telfair (T) County. Three other trees were selected in the Gulf Coast area by the Southern Institute of Forest Genetics (SIFG).

Selections were made subjectively. Each of the Dooly and Jones County selections was compared with 10 neighboring trees (table 1). Selected trees were visibly free of fusiform rust (Cronartium fusiforme Hedgc. and Hunt ex Cumm.), except three trees in Jones County (J7, J8, and J17) which were selected because they were rust infected.

Jones County selections were in an 18-year-old plantation of several acres. Measurements from 25 selected and 250 check trees (assumed to vary randomly in size) were used to estimate population parameters for that plantation (table 2).

The Dooly County plantations ranged in age from 14 to 18 years. It seems reasonable to assume that the population structure was similar to that in Jones County, but judging from comparisons with check trees (table 1), selection intensities for tree size were higher in Dooly than in Jones County. No data are available for judging the other selections, but they were phenotypically superior trees.

Table 1.--Comparisons of parent trees with 10 adjacent check trees

Selected tree		Superiority to check trees	
County	Number	Height	D.b.h.
		- - - - Percent - - - -	
Dooly (D)	2	20	16
	3	19	24
	8	18	37
	12	21	12
	13	15	30
	16	11	39
	17	12	30
	26	19	34
	27	16	13
	28	16	41
	31	14	54
	33	8	15
	35	13	37
	36	20	40
	37	20	37
	101	6	36
	103	13	28
Jones (J)	1	11	11
	2	12	40
	3	9	9
	4	12	7
	5	4	11
	6	10	-8
	7	6	20
	8	-15	-13
	9	8	14
	10	0	-11
	11	17	25
	12	18	8
	13	-22	-31
	14	15	10
	15	21	19
	16	-9	5
	17	13	13
	18	5	-6
	19	22	6
	20	18	-4
	22	37	51
	23	39	37
	24	11	13
Bleckley (B)[1]	12		
Clarke (C)	4		
	7		
Telfair (T)	12		
	21		
SIFG (IG)	8-7		
	17-1		
	18-4		

[1]Phenotypic comparisons not available for the remainder of the trees in this list.

Table 2.--Estimates of population parameters, selected mean, and standardized selection intensities for Jones County trees

	Total height	D.b.h.	Volume per tree
	Feet	Inches	Cubic feet
Population mean	50.00	11.75	20.10
Population standard deviations	8.16	2.41	9.64
Selected mean	54.24	12.80	25.13
		Standard deviations	
Selection intensity	0.52	0.43	0.52

Wind-pollinated seeds were collected from the trees and planted in an experimental nursery. The 49 half-sib families were planted in study plantations 38, 39, and 46. One check lot and four families were common to all three plantations.

Control district check lots (Cont. D. 5, etc.) were set up by the Georgia Forestry Commission as standard check lots for progeny testing pine seed orchard clones. Numbers correspond to Forestry Commission District numbers in effect in the early 1950's. Districts 5 and 6 are nearest the outplanting site in central Georgia. District 1 is in southeastern, District 2 in southwestern, and District 4 in west central Georgia. The commercial check lot (commer.) was nursery-run seedlings of unidentified provenance.

The field design was randomized complete blocks. Plantation 38 had three blocks of 25-tree square plots, plantation 39 had five blocks of 5-tree row plots, and plantation 46 had three blocks of 20-tree rectangular plots. Spacing was 10 by 10 feet. The planting sites were old fields in Bleckley County, Georgia, in the Upper Coastal Plain.

Data collected at 15 years were survival, height, d.b.h., and fusiform rust incidence, and the volume of each tree in plantation 38 was calculated (Schmitt and Bower 1970).

Standard two-way analyses of variance were performed on data from the different plantations. Heritabilities of height, d.b.h., and tree volume were estimated with data from plantation 38. No heritabilities were estimated with data from the other two plantations because family size in 39 was small and families from other states were included in 46.

RESULTS

Plantation 38

At 15 years of age, the 27 families and two check lots in plantation 38 differed in volume per plot (or per acre), height, survival, d.b.h., percent rust free, and volume per tree (table 3). Volume per acre varied from 2,343 to 404 cubic feet, height from 48.7 to 39.5 feet, survival from 64.1 to 11.8 percent, d.b.h. from 9.9 to 7.7 inches, rust free from 92.0 to 0.0 percent, and tree volume from 9.40 to 5.47 cubic feet (table 4).

Table 3.--Analyses of variance of 15-year data, plantation 38

Variance source	Degrees of freedom	Mean square	F ratio
VOLUME PER PLOT			
Block	2	408.1596	1.45^{ns}
Family	28	2,159.7469	7.69**
Error	55	280.8573	
HEIGHT			
Block	2	11.7624	2.08^{ns}
Family	28	10.5396	1.86*
Error	55	5.6570	
SURVIVAL			
Block	2	119.0096	3.76*
Family	28	266.7273	8.42**
Error	55	31.6846	
D.B.H.			
Block	2	.955350	2.74^{ns}
Family	28	.791218	2.27**
Error	55	.348044	
RUST FREE			
Block	2	12.1056	0.06^{ns}
Family	28	1,093.3229	5.78**
Error	55	188.9702	
VOLUME PER TREE			
Block	2	1.449350	1.13^{ns}
Family	28	2.666639	2.09*
Error	55	1.276585	

^{ns}Nonsignificant.
*Significant at the 5-percent level.
**Significant at the 1-percent level.

Table 4.--Data means at 15 years and multiple range tests for plantation 38[1]

Family	Volume per acre	Height	Survival	D.b.h.	Rust free	Tree volume
	Cubic feet	Feet	Percent	Inches	Percent	Cubic feet
D 17	2,343 a	48.7 a	62.3 a-b	9.3 a-d	53.8 b-d	9.16 a-b
J 18	2,093 a-b	45.2 a-c	64.1 a	8.9 a-e	77.4 a-b	7.97 a-e
D 33	1,659 b-c	44.9 a-c	50.7 a-e	9.0 a-e	68.5 a-c	7.93 a-e
J 3	1,612 b-d	45.2 a-c	58.7 a-c	8.1 d-f	40.7 b-e	6.70 c-f
D 26	1,606 b-d	45.1 a-c	58.7 a-c	8.1 e-f	65.8 a-c	6.74 c-f
D 36	1,577 b-e	43.2 b-d	53.3 a-d	8.6 b-f	92.0 a	7.26 a-f
J 14	1,514 c-f	45.1 a-c	49.3 a-f	8.6 b-f	65.1 a-c	7.54 a-f
J 6	1,397 c-g	41.8 b-d	52.2 a-d	8.4 b-f	8.9 e-g	6.52 d-f
J 7[3]	1,366 c-g	43.5 b-d	41.3 c-h	9.1 a-e	9.7 a-e	7.92 a-e
J 19	1,315 c-h	44.1 a-d	42.5 c-h	8.7 a-f	16.0 d-g	7.37 a-f
D 28	1,268 c-i	44.5 a-c	35.7 d-j	9.2 a-e	11.5 e-g	8.44 a-e
J 5	1,260 c-i	42.9 b-d	48.0 a-f	8.2 c-f	14.6 d-g	6.42 e-f
D 7	1,253 c-i	42.1 b-d	45.3 b-g	8.4 b-f	4.0 f-g	6.50 d-f
Cont. D. 5	1,087 d-j	42.2 b-d	38.5 d-i	8.6 b-f	12.4 e-g	7.02 b-f
D 37	1,068 d-j	44.3 a-c	38.6 d-i	8.3 c-f	20.9 d-g	6.92 b-f
J 12	1,037 e-j	46.6 a-b	35.9 d-j	8.1 e-f	6.7 e-g	6.80 c-f
D 12	998 f-k	46.3 a-b	29.1 g-l	9.0 a-c	3.7 f-g	7.88 a-e
J 17[3]	958 f-l	44.1 a-d	26.4 h-l	9.5 a-b	4.1 f-g	8.83 a-c
J 16[2]	946 g-l	41.4 c-d	32.0 f-k	8.7 a-f	10.2 e-g	7.14 a-f
J 20	929 g-l	42.9 b-d	32.5 e-k	8.5 b-f	27.9 c-f	7.33 a-f
J 2	927 g-l	44.2 a-d	22.3 i-m	9.9 a	21.4 d-f	9.40 a
D 8	841 g-l	43.4 b-d	22.4 i-m	9.5 a-b	7.0 e-g	8.74 a-d
J 24	787 h-l	42.4 b-d	22.1 i-m	9.3 a-e	20.2 d-g	7.94 a-e
D 35	709 i-l	43.2 b-d	17.8 k-m	9.3 a-d	14.5 d-g	8.48 a-e
Commer.	700 i-l	42.5 b-d	22.2 i-m	9.0 a-e	10.1 e-g	7.80 a-e
D 31	564 j-l	45.2 a-c	15.8 l-m	9.3 a-c	.0 g	9.10 a-b
J 8[2 3]	516 j-l	40.7 c-d	17.3 k-m	8.8 a-f	2.4 f-g	7.24 a-f
D 13	448 k-l	39.5 d	20.9 j-m	7.7 f	.0 g	5.47 f
D 103	404 l	43.8 b-d	11.8 m	9.2 a-e	.0 g	8.03 a-e
Average	1,145	43.8	36.1	8.8	19.2	7.61

[1]Means not sharing a common letter are different at the 5-percent level, Duncan's New Multiple Range Test.
[2]Parents inferior in size to average neighboring tree.
[3]Parents infected with fusiform rust.

Webb and Barber (1966) reported a 46-percent average improvement in volume per acre of these families over check lots at 8 years in plantation 38. At 15 years the average improvement over checks in volume per acre was 30 percent. The average volume per acre of the best 10 families, however, was 84 percent greater than the average of the two check lots. Families from selected trees, on the average, showed some gain in volume per tree and height but none in d.b.h. at 15 years, although the best 10 families showed moderate gains in all three of these traits. Gains in survival and rust resistance were appreciable, especially in the best 10 families in each category (table 5).

Individual tree data from plantation 38 were analyzed for estimating variance components and heritabilities for height, d.b.h., and tree volume. Narrow-sense heritability estimates were 0.27 for height and d.b.h. and 0.24 for volume per tree (table 6). The heritability estimate for tree volume at age 8 was 0.16 (Webb and Barber 1966).

Table 5.--Improvement of families over check lots in plantation 38

Trait	All families	Highest 10
	- - - - - - Percent - - - - - -	
Height	3.7	7.8
D.b.h.	.0	6.4
Volume per tree	2.8	16.2
Survival	20.3	78.8
Rust resistance [1]	9.6	47.4
Volume per acre	30.1	84.4

[1] Gain in rust resistance is expressed as the decrease in percent of infected trees.

Table 6.--Analysis of variance form, variance components, heritability estimates, and their standard errors for height, d.b.h., and tree volume in plantation 38

Source	d.f.	Expected mean squares
Block	2	$\sigma^2 + 11.2942\ \sigma^2_e + 251.7173\ \sigma^2_b$
Family	26	$\sigma^2 + 9.7409\ \sigma^2_e + 27.8503\ \sigma^2_f$
Error	51	$\sigma^2 + 9.0340\ \sigma^2_e$
Residual	673	σ^2
Total	752	

Variance components and their standard errors

Component	Height	D.b.h.	Volume
Block (σ^2_b)	0.0482 ± 0.1593	0.0129 ± 0.0159	0.0062 ± 0.0263
Family (σ^2_f)	2.2841 ± 1.0495	0.1698 ± 0.0700	0.6148 ± 0.2428
Error (σ^2_e)	1.1717 ± 0.8964	0.0004 ± 0.0527	0.0000 ± 0.1715
Residual (σ^2)	30.2338 ± 1.1637	2.3587 ± 0.0908	9.5824 ± 0.3680

Heritability estimates[1] and their standard errors

Height	D.b.h.	Volume
0.27 ± 0.12	0.27 ± 0.11	0.24 ± 0.09

[1] $h^2 = \sigma^2_A \div (\sigma^2_w + \sigma^2_e + \sigma^2_A)$

$\sigma^2_A = 4\sigma^2_f$

$\sigma^2_w = \sigma^2 - 3/4\ \sigma^2_A$.

Plantation 39

The 23 families and three check lots in plantation 39 differed in volume per acre, height, and survival but not in d.b.h. and percent rust free (table 7). Family averages ranged from 3,459 to 801 cubic feet for volume per acre, 52.1 to 41.1 feet for height, 77.7 to 13.1 percent for survival, 10.0 to 7.7 inches for diameter, and 67.2 to 0.0 percent for rust free (table 8).

Table 7.--Analyses of variance of 15-year data, plantation 39

Variance source	Degrees of freedom	Mean square	F ratio
VOLUME PER PLOT			
Block	4	9.7533	0.11^{ns}
Family	25	248.4328	2.84**
Error	93	87.4431	
HEIGHT			
Block	4	25.5005	5.22**
Family	25	27.2790	5.58**
Error	93	4.8849	
SURVIVAL			
Block	4	321.3263	1.37^{ns}
Family	25	547.1731	2.32**
Error	93	235.0928	
D.B.H.			
Block	4	.3966	.28^{ns}
Family	25	1.9554	1.40^{ns}
Error	93	1.3953	
RUST FREE			
Block	4	435.1728	.50^{ns}
Family	25	1,120.2268	1.30^{ns}
Error	93	862.3716	

^{ns}Nonsignificant.
**Significant at the 1-percent level.

Table 8.--Data means at 15 years and multiple range tests for plantation 39[1]

Family	Volume per acre	Height	Survival	D.b.h.	Rust free
	Cubic feet	Feet	Percent	Inches	Percent
D 16	3,459 a	50.3 a-b	76.4 a	9.7 a	67.2 a
J 5	2,701 a-b	46.7 c-f	60.4 a-c	9.0 a	27.5 a
D 36	2,335 b-c	45.9 c-h	68.8 a-b	9.2 a	58.6 a
J 22	2,317 b-c	45.3 c-h	56.4 a-d	9.4 a	41.4 a
J 13[2]	2,195 b-d	47.9 b-e	52.4 a-d	9.7 a	48.1 a
C 4	2,195 b-d	48.0 b-d	47.6 a-e	10.0 a	62.1 a
J 10[2]	2,108 b-d	45.6 c-h	68.8 a-b	8.6 a	12.8 a
J 11	1,960 b-e	46.6 c-g	52.0 a-d	9.1 a	2.4 a
J 21	1,803 b-e	45.3 c-h	56.4 a-d	8.8 a	50.0 a
J 1	1,786 b-e	46.8 c-f	56.4 a-d	8.7 a	48.4 a
D 2	1,768 b-e	41.1 i	77.7 a	7.7 a	5.7 a
B 12	1,585 b-e	44.5 e-h	52.0 a-d	8.5 a	14.1 a
Cont. D. 4 (Lob.)	1,525 b-e	44.7 d-h	30.8 b-e	8.9 a	13.6 a
J 4	1,525 b-e	44.6 e-h	47.6 a-e	8.2 a	31.3 a
J 15	1,507 b-e	52.1 a	23.3 c-e	9.6 a	48.6 a
D 12	1,420 c-e	43.2 h-i	43.6 a-e	9.0 a	9.6 a
D 101	1,411 c-e	43.4 f-i	39.6 a-e	9.4 a	12.8 a
D 27	1,307 c-e	48.5 b-c	30.4 b-e	8.1 a	3.6 a
J 6	1,272 c-e	45.0 d-h	47.6 a-e	7.8 a	15.4 a
J 24	1,167 c-e	46.5 c-h	22.9 c-e	9.3 a	30.4 a
D 3	1,141 c-e	45.9 c-h	27.5 c-e	9.2 a	2.4 a
Cont. D. 5	1,124 c-e	45.0 d-h	39.4 a-e	8.4 a	36.5 a
J 23	1,080 c-e	45.1 d-h	39.6 a-e	8.2 a	34.6 a
J 9	984 d-e	43.3 g-i	39.2 a-e	8.1 a	9.6 a
C 7	941 d-e	44.7 d-h	19.7 d-e	8.7 a	.0 a
Commer.	801 e	47.0 c-e	13.1 e	9.5 a	16.5 a
Average	1,673	45.8	45.5	8.9	29.1

[1] Means not sharing a common letter are different at the 5-percent level, Duncan's New Multiple Range Test.

[2] Parents inferior in size to average neighboring tree.

The families from selected trees, on the average, showed considerable increase over check lots in survival, rust resistance, and volume production per acre at age 15, but no increase in height or diameter. The average of the best eight families, however, showed moderate increases over check lots in height and diameter and large increases in survival, rust resistance, and volume per acre (table 9).

Table 9.--Improvement of families over check lots in plantation 39

Trait	All families	Highest 8
	Percent	
Height	0.6	6.1
D.b.h.	-0.4	6.8
Survival	72.2	134.6
Rust resistance[1]	10.0	39.6
Volume per acre	51.4	109.5

[1] Gain in rust resistance is expressed as the decrease in percent of infected trees.

Plantation 46

In plantation 46 the 11 families and four check lots differed in all traits evaluated (table 10). Averages varied from 2,363 to 941 cubic feet for volume per acre, 46.7 to 37.7 feet for height, 85.2 to 39.7 percent for survival, 8.9 to 7.0 inches for d.b.h., and 85.3 to 6.7 percent for rust free (table 11).

Table 10.--Analyses of variance of 15-year data, plantation 46

Variance source	Degrees of freedom	Mean square	F ratio
VOLUME PER PLOT			
Block	2	248.1254	1.39^{ns}
Family	14	944.2690	5.27**
Error	28	178.8883	
HEIGHT			
Block	2	1.8909	0.54^{ns}
Family	14	12.6185	3.64**
Error	28	3.4654	
SURVIVAL			
Block	2	139.7588	3.11^{ns}
Family	14	156.9424	3.50**
Error	28	44.8805	
D.B.H.			
Block	2	.7873	3.78*
Family	14	.5677	2.72*
Error	28	.2085	
RUST FREE			
Block	2	92.7991	.82^{ns}
Family	14	539.6911	4.79**
Error	28	112.5437	

^{ns}Nonsignificant.
*Significant at the 5-percent level.
**Significant at the 1-percent level.

Table 11.--Data means at 15 years and multiple range tests for plantation 46[1]

Progeny	Volume per acre	Height	Survival	D.b.h.	Rust free
	Cubic feet	Feet	Percent	Inches	Percent
IG 8-7	2,363 a	46.7 a	85.2 a	8.0 b	85.3 a
Cont. D. 6 (Lob.)	1,797 b	43.9 a-b	70.5 a-b	8.1 b	40.8 b
T 12	1,736 b-c	45.9 a-b	51.7 b-e	8.9 a	18.6 b-d
Cont. D. 5	1,548 b-d	43.7 a-b	58.5 b-e	8.1 a-b	20.5 b-d
J 5	1,538 b-d	43.1 a-b	66.7 b-d	7.6 b-c	26.3 b-d
T 21	1,531 b-d	45.3 a-b	67.4 b-c	7.5 b-c	49.6 b
IG 17-1	1,420 b-e	43.2 a-b	61.5 b-e	7.6 b-c	31.3 b-d
J 6	1,405 b-e	45.2 a-b	60.0 b-e	7.5 b-c	45.6 b
J 24	1,276 b-e	43.5 a-b	53.4 b-e	7.8 b-c	22.2 b-d
D 35	1,180 c-e	43.0 b	50.0 b-e	7.8 b-c	6.8 d
Cont. D. 2	1,139 d-e	42.9 b	52.0 b-e	7.4 b-c	34.0 b-c
IG 18-4	1,117 d-e	44.0 a-b	44.8 d-e	7.9 b-c	8.8 c-d
J 8[2]	950 e	42.8 b	39.7 e	7.6 b-c	26.0 b-d
Cont. D. 1	947 e	37.7 c	46.7 c-e	7.4 b-c	38.8 b
D 12	941 e	42.4 b	48.3 b-e	7.0 c	6.7 d
Average	1,394	43.5	57.5	7.7	29.4

[1]Means not sharing a common letter are different at the 5-percent level, Duncan's New Multiple Range Test.
[2]Parent inferior in size to average neighboring tree; also infected with fusiform rust.

On the average, the 11 families in plantation 46 showed little or no gain over the average of the four check lots in diameter growth rate, rust resistance, height, survival, and volume per acre. The best four progenies showed moderate to good gain over check lots in all these variables (table 12).

Table 12.--Improvement of families over check lots in plantation 46

Trait	All families	Highest 4
	- - - - - - Percent - - - - - -	
Height	4.7	8.8
D.b.h.	-0.9	5.2
Survival	1.4	23.3
Rust resistance[1]	-8.5	32.8
Volume per acre	3.6	31.9

[1]Gain in rust resistance is expressed as the decrease in percent of infected trees.

DISCUSSION

The gains over check lots of these progenies from mass-selected trees were large enough to show that mass selection is an effective method for improving slash pine. However, average gains were lower than they would have been had not some phenotypically inferior parent trees been included, some of which proved to be genetically inferior. Superiorities of the better families, as shown in tables 5, 9, and 12, probably more nearly reflect gains that can be expected from a rogued seed orchard, although gains in volume per unit area are somewhat higher than gains predicted in a number of studies of the progeny-tested seed orchard approach to improvement of the southern pines (Einspahr 1972).

These gains may reflect an undetermined amount of provenance effect in the check lots. However, the control district 5 check lot used in all three plantations was collected near the test site, as was the control district 4 loblolly check lot. Any provenance effect in gain comparisons is probably small. Some loblolly check lots were used because loblolly pine is a good alternative to slash pine for planting in the study area.

The trees selected in Dooly and Jones Counties show a wide range in size comparison with 10 neighboring trees (table 1), but they are not a random sample of slash pine. Therefore the heritability estimates in table 6 apply only to this set of parents. The experimental design may also affect the estimates. However, these heritabilities are similar to a number of heritabilities of tree size and volume reported for other studies, and do not seem unreasonably high (Barber 1964; Matziris and Zobel 1973; Stonecypher et al. 1973).

After the Dooly and Jones County trees were selected by subjective methods they were compared with 10 neighboring trees. Is the check-tree comparison method useful for ranking selected trees and for predicting their relative potentials? To answer that question, heights and diameters of progenies in plantation 38 were ranked. The height and diameter superiority percentages of the parents over check-tree averages also were ranked. Spearman's coefficient of rank correlation (Steel and Torrie 1960, p. 409) between parent and progeny was calculated. The coefficients were 0.40 and 0.41 for height and diameter, respectively, both significant at the 5-percent level (table 13).

Table 13.--Test of rank correlation between parent[1] and progeny for height and d.b.h. at 15 years, plantation 38

Family	Height		Family	D.b.h.	
	Family rank	Parent rank		Family rank	Parent rank
D 17	1	15.5	J 2	1	3.5
J 12	2	7	D 8	2	6
D 12	3	2	J 17	3	14.5
J 18	4	22	D 31	4	1
J 3	5	19	D 17	5.5	9.5
D 31	6	11	D 35	5.5	6
D 26	7	5	J 24	7	14.5
J 14	8	10	D 28	8.5	2
D 33	9	20	D 103	8.5	11
D 28	10	9	J 7	10	12
D 37	11	3.5	D 12	11.5	16
J 2	12	15.5	D 33	11.5	13
J 17	13	13	J 18	13	24
J 19	14	1	J 8	14	26
D 103	15	13	J 16	15	22
J 7	16	21	J 19	16	21
D 8	17	7	D 36	17	3.5
D 35	18	13	J 14	18	18
D 36	19	3.5	J 20	19	23
J 20	20	7	J 6	20	25
J 5	21	23	D 37	21	6
J 24	22	17	J 5	22	17
J 6	23	18	J 3	23	19
J 16	24	24	J 12	24	20
J 8	25	25	D 26	25	8
D 13	26	26	D 13	26	9.5
	$\underline{2}/ r_s = 0.40^*$			$\underline{2}/ r_s = 0.41^*$	

1/ Parents were ranked according to their superiorities over their 10 neighboring trees.
2/ Spearman's coefficient of rank correlation.
* Significant at the 5-percent level.

Apparently the check-tree method is useful for ranking selected trees, but is subject to error. For example, J18 ranked 22nd out of 26 in height by the check-tree method, but its progeny ranked fourth in height in plantation 38. The d.b.h. ranking for J18 was 24th by the check-tree method and 13th by its progeny (table 13). J18 produced a relatively faster growing progeny than predicted by check-tree comparisons. It was selected primarily for its excellent form. Conversely, D36 produced a relatively slower growing progeny than predicted by check-tree comparison. That selection ranked 3.5 in superiority over check trees in both height and diameter but its progeny ranked 19th and 17th, respectively, in height and diameter growth. Progenies from some parents performed about as expected in one trait but not in another. For example, D17 ranked 9.5 in diameter superiority over check trees and 5.5 in progeny diameter growth, whereas rankings for height were 15.5 by check tree and 1st by progeny growth. The check-tree method is effective, but progeny testing is necessary for an accurate evaluation of selections.

The most important gain shown in this study was in fusiform rust resistance. The plantations were in an area of high rust incidence, so all progenies were thoroughly exposed to inoculum. The gains over check lots appear to be at least as great as gains predicted for loblolly pine with selection and progeny testing (Blair 1970). Fusiform rust is a severe problem in slash and loblolly pines and selection for resistance looks so promising that special seed orchards of rust-resistant clones are being established by some forest industries (Zobel et al. 1971).

Most of the selected trees in this study were free of rust, but three of the Jones County trees were selected because they were infected (J7, J8, J17). Progenies of all infected parents were heavily infected with rust. Dinus (1971) found that most infected trees selected from a heavily infected plantation produced susceptible, open-pollinated progenies, whereas progenies from the rust-free selections were more resistant to artificial inoculation than the controls. Apparently the inoculum levels in the plantations where these parents were selected had not been sufficient to infect all susceptible trees, because several of the progenies from apparently rust-free selections were heavily infected.

The small plots in conjunction with few replications (small family size) may have caused the lack of significance among progenies in d.b.h. and rust-free percentages in plantation 39 (table 7). The range in family averages in each of these two traits was about the same in plantation 39 as in the other two plantations with larger plots, but the large error variances with the five-tree plots prevented the showing of significance in differences among families in d.b.h. and rust-free percentages. Error variances in comparison with the means were considerably larger in plantation 39 than in plantations 38 and 46 for all the traits measured except tree height, as shown by the coefficients of variation (C. V.) in table 14. The C. V. for rust-free percentages was particularly high in plantation 39. Tests for homogeneity of variances showed that the error variances for survival percentages, d.b.h., and rust-free percentages were highly significantly greater in plantation 39 (5-tree plots) than in plantations 38 (25-tree plots) and 46 (20-tree plots). Error variances for height did not differ significantly among plantations. Furthermore, there were no significant differences between error variances in plantation 38 and plantation 46 for any of the traits, so greater error variance except in height apparently is a disadvantage to five-tree plots, unless the number of replications is increased sufficiently to increase family size to an adequate level.

Some of these progenies are good sources of material for further breeding work, and some second-generation selections have been made (table 15). Selection among families was primarily on the basis of rust resistance, with some consideration given to volume per acre. Individuals within families were selected for freedom from rust, tree size, stem straightness, and general appearance of the crown. These selections are being established in a rust-resistant clone bank for use in future breeding.

Table 14.--Coefficients of variation (C. V.) in 15th-year data for plantations 38, 39, and 46

Trait	Plantation		
	38 (25-tree plots)	39 (5-tree plots)	46 (20-tree plots)
Volume per plot	25.5	48.8	20.9
Height	5.4	4.8	4.3
D. b. h.	6.7	13.3	5.9
Survival	15.2	36.2	13.6
Rust free	5.3	100.7	32.3

Table 15.--Superiorities of second-generation selections made in plantations 38, 39, and 46

PLANTATION 38

Selected tree		Trait				
		Family over check lots				Tree over plot or family[1]
I. D.	Parentage	Rust resistance[2]	Height	D. b. h.	Volume per acre	Tree volume
		- - - - - - - Percent - - - - - - -				
1668-20	J 3 X W	33	7	-8	80	35
1710-24	J 14 X W	61	6	-2	69	54
1699-24	J 18 X W	74	7	1	134	53
1655-18	D 17 X W	48	15	6	162	10
1679-25	D 26 X W	61	6	-8	80	63
1688-15	D 33 X W	64	6	2	86	85
1663-11	D 36 X W	91	1	-2	76	61
PLANTATION 39						
1771-1	J 1 X W	34	3	-3	55	5
1831-4	J 21 X W	36	-1	-1	57	31
1842-1	D 16 X W	58	10	8	201	70
1863-3	D 36 X W	47	1	3	103	2
PLANTATION 46						
2738-9	T 21 X W	24	8	-3	13	36
2745-4	IG 8-7 X W	78	11	3	74	78

[1]Tree over plot average in plantations 38 and 46 (large plots) and tree over family average in plantation 39 (small plots).

[2]Superiorities in rust resistance are expressed as the decrease in percent of infected trees.

LITERATURE CITED

Barber, John C.
1964. Inherent variation among slash pine progenies at the Ida Cason Callaway Foundation. U.S. For. Serv. Res. Pap. SE-10, 90 p. Southeast. For. Exp. Stn., Asheville, N.C.

Blair, Roger Lee
1970. Quantitative inheritance of resistance to fusiform rust in loblolly pine. Ph. D. Diss., N.C. State Univ., Raleigh, 87 p.

Dinus, Ronald J.
1971. Phenotypic selection for fusiform rust resistance. Eleventh Conf. South. For. Tree Improv. Proc. 1971:68-75.

Einspahr, Dean W.
1972. Forest tree improvement and the pulp and paper industry. Tappi 55: 1660-1669.

Matziris, D. I., and B. J. Zobel
1973. Inheritance and correlations of juvenile characteristics in loblolly pine (Pinus taeda L.). Silvae Genet. 22:38-45.

Schmitt, Dan, and Dave Bower
1970. Volume tables for young loblolly, slash, and longleaf pines in plantations in south Mississippi. USDA For. Serv. Res. Note SO-102, 2 p. South. For. Exp. Stn., New Orleans, La.

Steel, Robert G. D., and James H. Torrie
1960. Principles and procedures of statistics. 481 p. McGraw-Hill, New York.

Stonecypher, Roy W., Bruce J. Zobel, and Roger Blair
1973. Inheritance patterns of loblolly pines from a nonselected natural population. N.C. Agric. Exp. Stn. Tech. Bull. 220, 53 p.

Webb, Charles D., and John C. Barber
1966. Selection in slash pine brings marked improvement in diameter and height growth plus rust resistance. Eighth South. Conf. For. Tree Improv. Proc. 1965:67-72.

Zobel, Bruce, Roger Blair, and Marvin Zoerb
1971. Using research data--disease resistance. J. For. 69:486-489.

Sluder, Earl R.

1975. Fifteenth-year results from progeny tests of slash pine. USDA For. Serv. Res. Pap. SE-140, 15 p. Southeast. For. Exp. Stn., Asheville, N.C.

At 15 years, open-pollinated families from 49 selected slash pine trees differed in volume per plot, survival, percent rust free, volume per tree, d.b.h., and height. They showed good gains over check lots in survival, rust resistance, and volume per acre, and moderate gains in volume per tree, height, and d.b.h. Heritabilities in one plantation containing 27 progenies were 0.27 for height and d.b.h. and 0.24 for volume per tree.

Sluder, Earl R.

1975. Fifteenth-year results from progeny tests of slash pine. USDA For. Serv. Res. Pap. SE-140, 15 p. Southeast. For. Exp. Stn., Asheville, N.C.

At 15 years, open-pollinated families from 49 selected slash pine trees differed in volume per plot, survival, percent rust free, volume per tree, d.b.h., and height. They showed good gains over check lots in survival, rust resistance, and volume per acre, and moderate gains in volume per tree, height, and d.b.h. Heritabilities in one plantation containing 27 progenies were 0.27 for height and d.b.h. and 0.24 for volume per tree.

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DA Forest Service Research Paper SE-141 October 1975

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The slash pine (Pinus elliottii Engelm.) ecosystem is capable of producing an estimated 1 billion cubic feet of net annual growth per year in entire boles, inside the bark, in well-stocked, natural stands and plantations. This production is an estimate of the biological potential for timber production on the 11.7 million acres occupied by slash pine east of the Mississippi River. This biological potential is 1.5 times larger than the periodic annual growth and is 2.8 times the estimated rate of removals. Our findings indicate the average rate of removals in cubic volume can be doubled in about 30 years without adding additional acres to the ecosystem.

Achieving this biological potential requires reforestation of every harvested slash pine stand to full stocking and delaying harvest until about age 30.

In this report the slash pine ecosystem east of the Mississippi River is defined. An estimate is made of the biological potential for timber production by Timber Production Provinces. Important limitations to capturing the biological potential are identified. The findings of this research should help in developing action and research programs that can most effectively increase timber production over large areas while maintaining other forest benefits.

DEFINITION OF THE SLASH PINE ECOSYSTEM

The slash pine ecosystem is a collection of physical and chemical environments, trees, shrubs, small plants, animals, and people. It is defined as all commercial forest stands, natural and planted, in which pines make up half or more of the growing stock and slash is the predominant pine. This ecosystem has a range within which the stands occupy certain habitats and each habitat has a biological potential for producing slash pine timber and other forest benefits. The slash pine stands are interspersed among stands belonging to other forest ecosystems. Only about 1.5 percent of the slash pine growing-stock volume is in other ecosystems, and within the slash pine ecosystem, associated species, mostly hardwoods, make up less than 1 percent of the growing-stock volume.

Within the United States the natural range of slash pine is limited to the coastal and rolling Piedmont areas from southeastern South Carolina to southeastern Louisiana and south through Florida (fig. 1) (Sternitzke and Nelson 1970). A variety, P. elliottii var. densa Little & Dorman, has been recognized in south Florida (Little and Dorman 1952).

The range of the ecosystem has been extended by planting from southeastern North Carolina to eastern Texas; however, the largest increases in timber production outside of the natural range are in South Carolina and Georgia (fig. 2). The North Carolina plantings have been about 19 million cubic feet of timber in trees less than 11 inches in diameter. Plantations are also being established west of the Mississippi River (Mann 1971; Enghardt and Mann 1972; Mann and Enghardt 1972). However, the potential of these areas to produce large volumes of timber from slash pine plantations is yet to be proven.

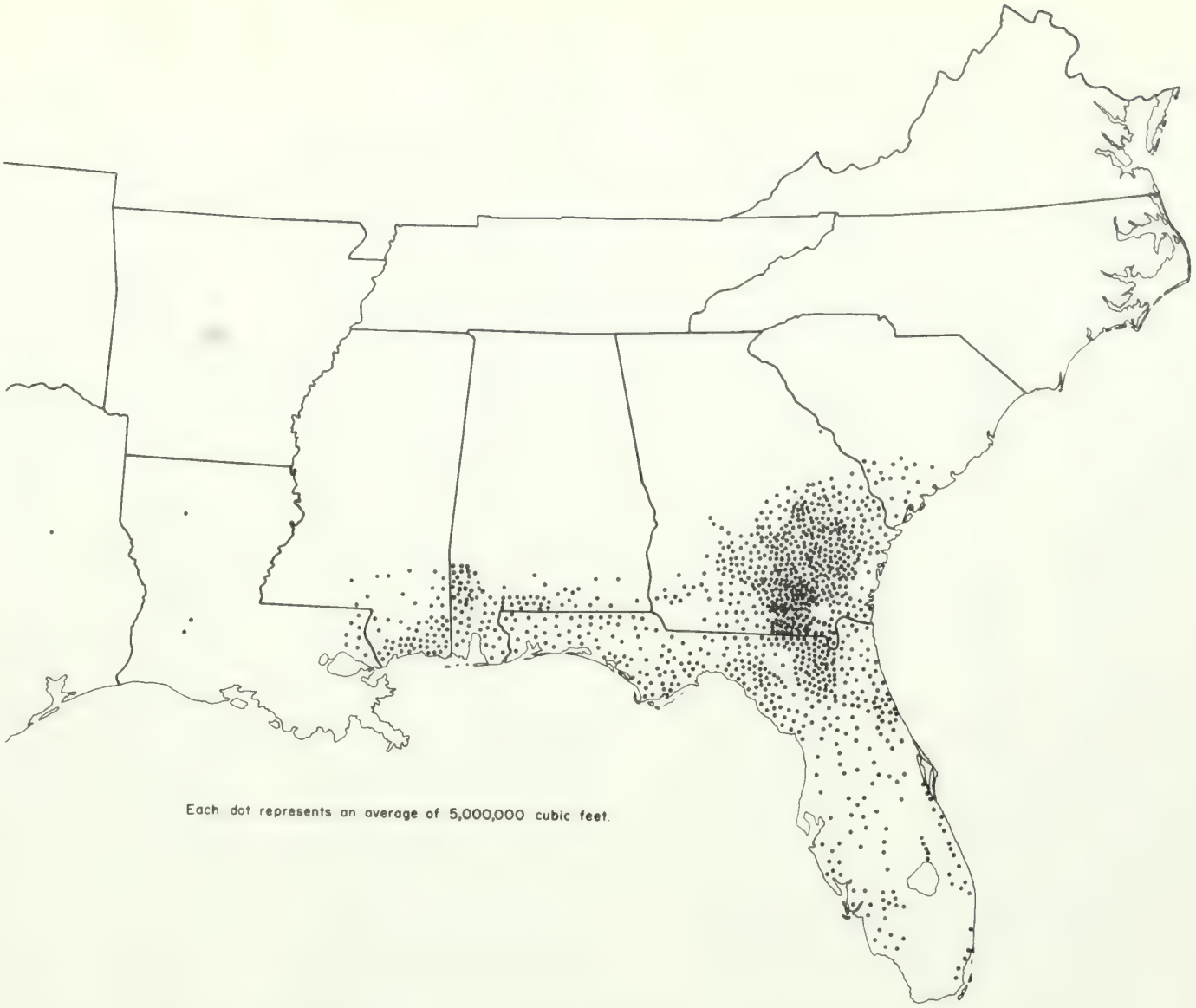

Figure 1. --Distribution of slash pine growing stock in relation to the natural range (Sternitzke and Nelson 1970).

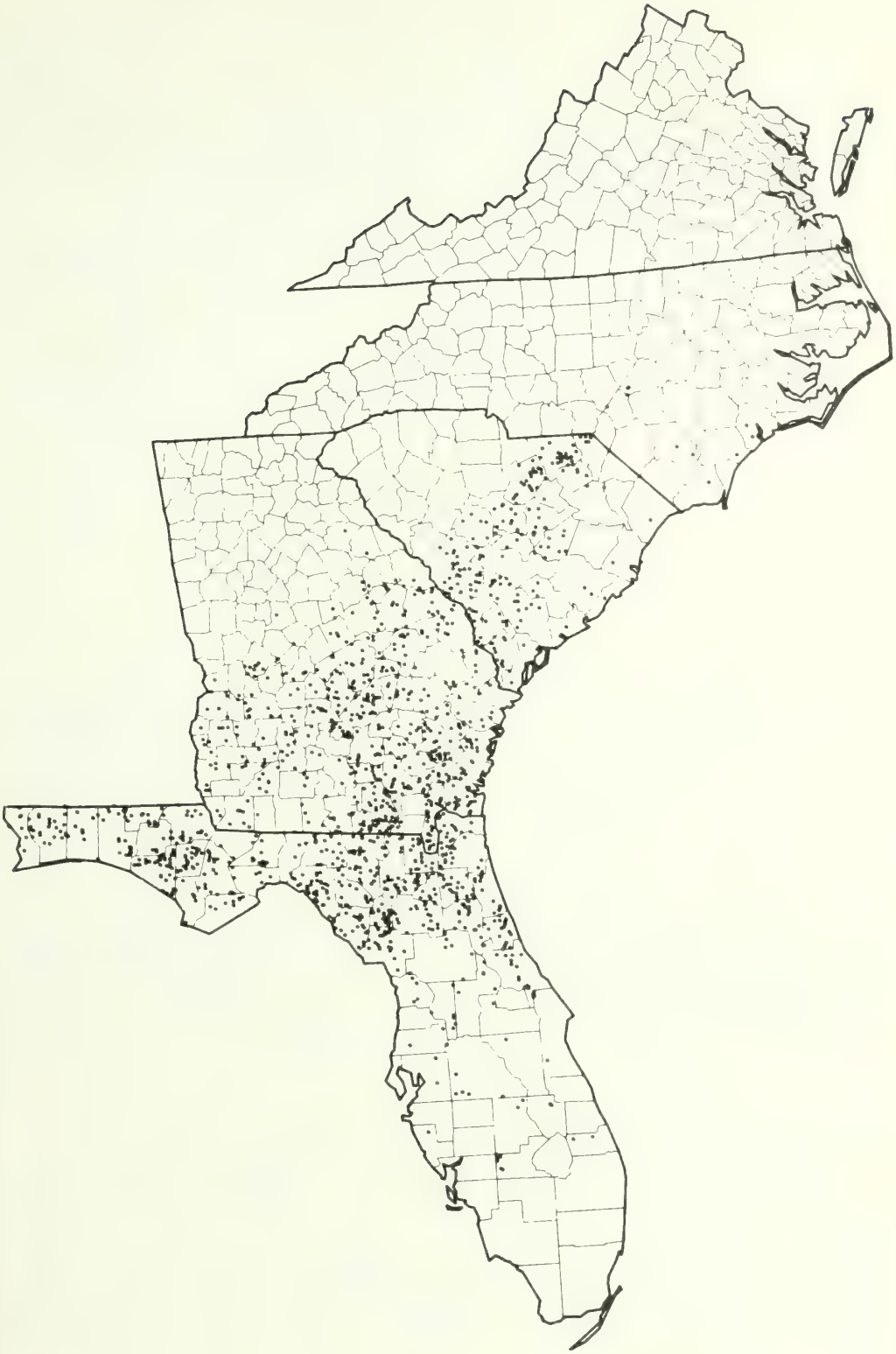

Figure 2. --Each dot represents the location of a slash pine plantation measured by the Forest Survey in Florida, Georgia, South Carolina, and North Carolina.

DEFINITION OF THE BIOLOGICAL POTENTIAL FOR TIMBER PRODUCTION

Although the biological potential for timber production has been a concern of forestry for many years, it has not been formally defined in Forest Terminology (Ford-Robertson 1971). Since the concept was only recently defined in relation to total organic matter production (Boyce 1975), some explanation of the meaning is required.

The total amount of organic matter produced in a forest is the gross primary production (fig. 3). A large part of the organic matter is used by green plants for respiration. The remainder is the net primary production that goes into wood, bark, flowers, fruits, roots, and leaves of both timber and nontimber parts of trees. Some of this material is eaten by animals or damaged by diseases, weather, fire, and other agents.

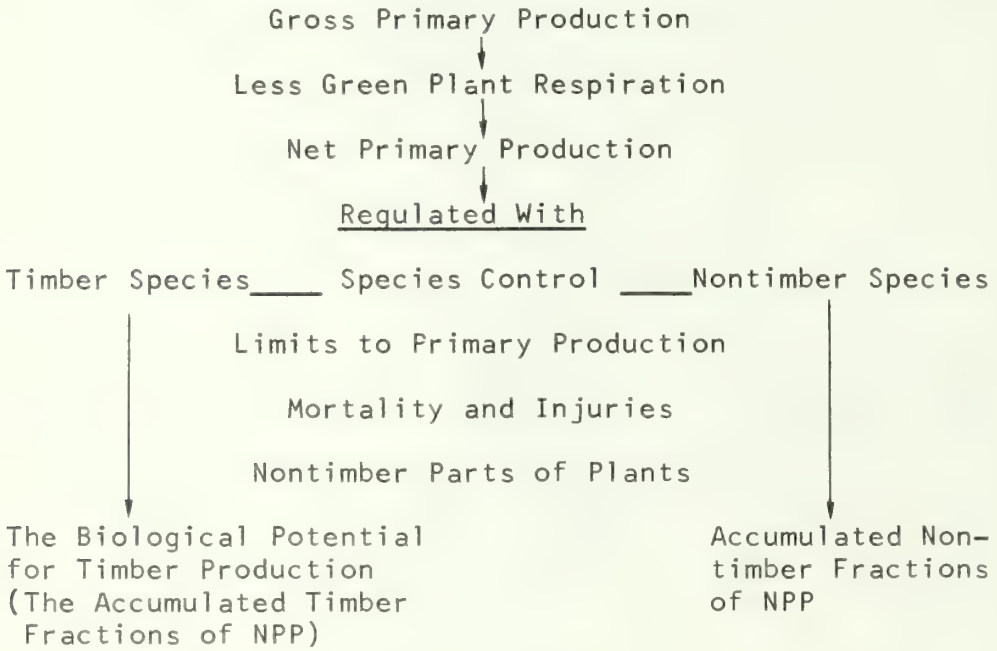

Figure 3.--The relationship of the biological potential for timber production to ecosystem production. Arrows indicate potential partitioning of organic matter.

The accumulated fractions of net primary production expected to become timber are the biological potential for timber production. This quantity can be stated as the amount of timber, limited only by biological constraints, that can be expected in a given time with specified silvicultural practices. This definition recognizes that timber is a fraction of ecosystem production and that silviculture can divert production of the ecosystem to or from timber, wildlife, or other segments of the system.

The silvicultural practices considered in this report are to maintain full stocking (Schumacher and Coile 1960) of both planted and natural stands on the lands where slash pine was found by the Forest Survey. Genetically superior trees and intensive silvicultural practices may increase the rate of height growth above that found on the Forest Survey plots. Information is not available to project the effects of intensive silviculture to the entire ecosystem. Our estimate of the biological potential is based on the assumption that the next rotation of slash pine trees will grow to the same height as the slash pine trees measured by the Forest Survey. The biological potential is essentially demonstrated by the rate of height growth of trees measured on Forest Survey plots.

It would be desirable to measure net primary production directly and use silviculture to divert appropriate amounts either within or among stands for timber, wildlife, and other benefits. Techniques are not available to make such measurements on millions of acres. We can, however, make some preliminary estimates of the biological potential for timber without knowing how much production is going into other parts of the ecosystem.

PROCEDURES

The biological potential, expressed as the annual accumulation of net primary production as timber, was estimated by multiplying the midpoint mean annual increment for each site index class by the number of acres in that class. This first estimate of the biological potential considers only silvicultural actions required to regenerate harvested stands and maintain them in a well-stocked condition to age 30.

To carry out this procedure it was necessary to establish (1) age for the culmination of mean annual increment for cubic volume, (2) stand density for well-stocked stands, and (3) expected yields for these stands. For this analysis, age 30 was accepted as the approximate age for culmination of mean annual increment. Stand density and yield information was taken from the data of Schumacher and Coile (1960). The reasons for these choices are explained in the following paragraphs.

The maximum mean annual accumulation of net primary production as cubic volume of timber is expected at the age of culmination of the mean annual increment for stands maintained at full stocking. For even-aged, natural and planted stands of slash pine, mean annual increments for cubic volume culminate between 25 and 30 years of age (USDA 1929; Schumacher and Coile 1960; Bennett and Clutter 1968). For plantations the mean annual increment culminates, in general, about age 25, and the growth rate continues or declines very little through age 30 (Bennett and Clutter 1968). For this study, 30 years was selected as the age for estimating the biological potential.

The question of full stocking for maximum accumulation of net primary production as timber has never been satisfactorily answered (Nelson and Bennett 1965). For slash pine stands there are some usable approximations based on concepts of normally stocked (USDA 1929) and well-stocked stands (Schumacher and Coile 1960). From these reports we can estimate the mean annual increments to age 30 for selected site index classes. However, the MAI values from Schumacher and Coile (1960) differ from those in MP-50--USDA Miscellaneous Publication 50 (1929)--by as much as 7 to 25 cubic feet (table 1). These differences are due to the larger basal areas for the MP-50 data than for the Schumacher and Coile data.

Table 1.--Estimated mean annual increment for well-stocked, natural slash pine stands, age 30, by site index class, basal area, and selected yield tables

Site index class 1/	Basal area MP-50 2/	MAI MP-50 3/	MAI Bennett 4/	Basal area Schumacher and Coile 5/	MAI Schumacher and Coile 6/	MAI Bennett 4/
	Square feet	Cubic feet		Square feet	Cubic feet	
50	--	--	--	97	47	--
60	152	83	74	104	62	56
70	156	105	101	111	80	74
80	158	125	127	120	100	99
90	159	143	151	130	124	123
100	160	160	174	143	153	157

1/ Height of dominant trees at age 50.
2/ Basal area per acre, table 133, USDA Misc. Publ. 50 (1929).
3/ MAI computed from table 136, USDA Misc. Publ. 50 (1929).
4/ MAI interpolated from table 3, Bennett (1970a).
5/ Basal area per acre, table 2, Schumacher and Coile (1960).
6/ MAI computed from table 2, Schumacher and Coile (1960).

Bennett (1970a) developed yield tables in which basal area is the measure of stand density. Mean annual increments at age 30 were computed from yields estimated by the Bennett equations for the site index classes and basal areas proposed for normally stocked and well-stocked stands. These values vary from those in MP-50 by from 2 to 9 cubic feet per year for individual site index classes (table 1). At site index 80 the mean annual increments vary by only 2 cubic feet. At lower site index classes the Bennett equations give smaller MAI's and above site index 80 larger MAI's.

When the basal areas for well-stocked stands as defined by Schumacher and Coile (1960) are entered in the Bennett (1970a) equations, the mean annual increments developed from these equations are not widely different from those estimated from Schumacher and Coile (table 1, fig. 4). A maximum difference of 6 cubic feet is indicated for site index classes 60 and 70 and only 1 cubic foot for classes 80 and 90. Thus, when appropriate basal areas are used, the Bennett equations are not widely different from either the MP-50 or the Schumacher and Coile data. Which basal areas represent full stocking? The answer cannot be derived from published information. For this study, the Schumacher and Coile data were accepted because site index values for the sample plots were directly related to these data.

The next procedural step was to apply these estimates of mean annual increments to the ecosystem. Forest Survey reports for growing-stock volume, growth, removals, and mortality are in cubic feet inside the bark from a 1-foot stump to a minimum 4.0-inch top diameter outside bark of the central stem, or to a point where the central stem breaks into limbs. These volumes were converted to cubic volume inside bark from the stump to tip for slash pine. An average multiplier of 1.11 was estimated from unpublished and published information (Beltz and Chappell 1973; Welch 1974).

Extension to the Ecosystem

The Forest Survey assigns sample plots to a site productivity class in terms of potential growth in cubic-foot volume per acre (USDA FS 1973). Since these are nationally used classes developed for a large number of species, the midpoint values of these productivity classes are not necessarily the same as the midpoint values for individual species. The national productivity classes were not used in this study. Precision was improved by relating the site productivity classes to site index classes and determining appropriate midpoint mean annual increments for these latter classes. For slash pine the national productivity classes were related to site index classes for slash pine as follows: the 25- to 50-cubic-foot national productivity class equals site index class 50 to 62 (fig. 4); the 50- to 85-cubic-foot class equals site index class 62 to 80; the 85- to 120-cubic-foot class equals site index class 80 to 93; the 120- to 165-cubic-foot class equals site index class 93 to 110; and the 165- to 225-cubic-foot class equals site index classes exceeding 110. Since very few slash pine stands have a site index larger than 100, the last two site index classes were combined to form only four site classes for this study. For these four site index classes, the midpoint mean annual increments interpolated from Schumacher and Coile mean annual increments at age 30 (table 1) were 56, 82, 114, and 141 cubic feet per acre in entire stem inside the bark (fig. 4).

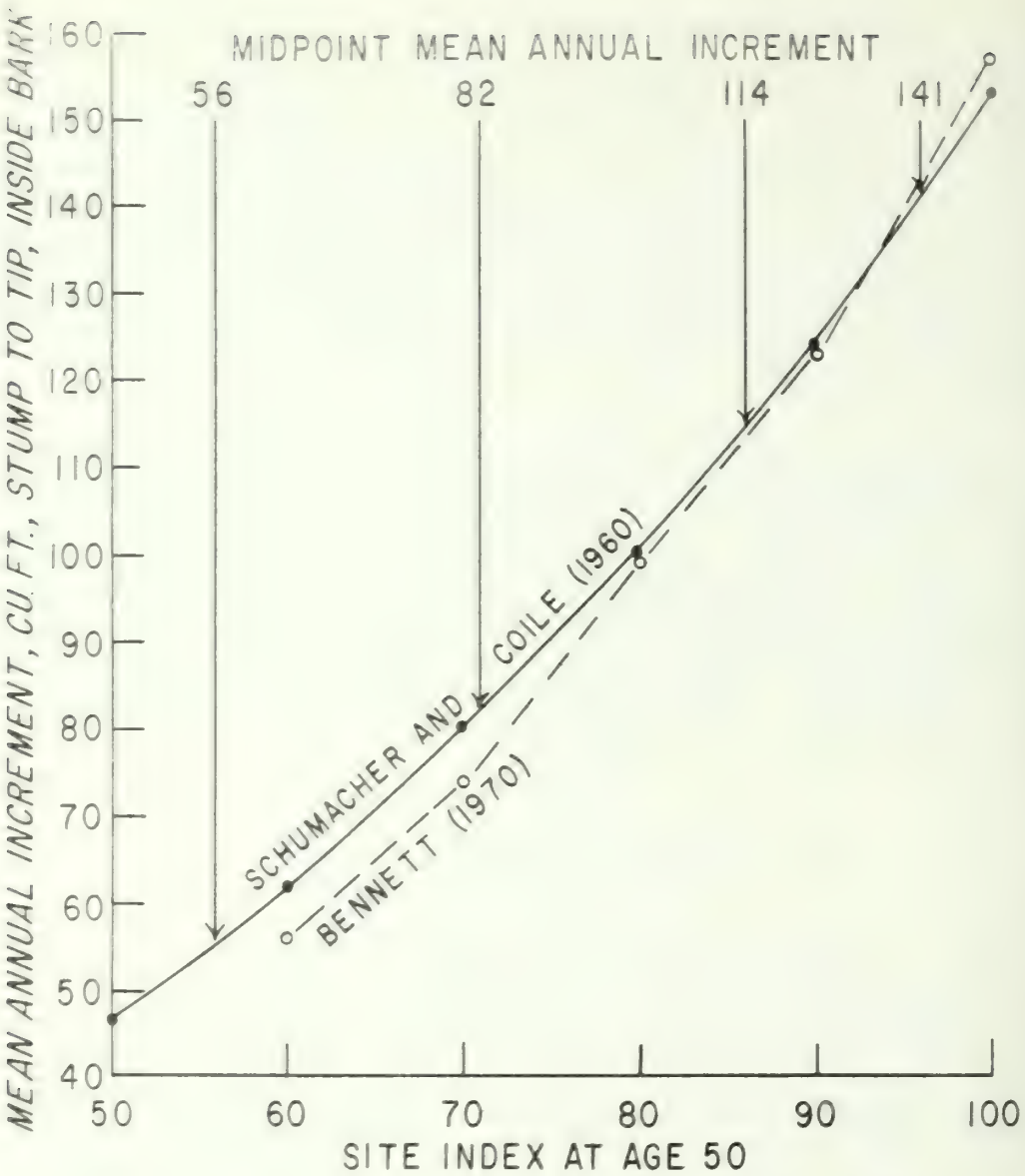

Figure 4.--For four site index classes, the midpoint mean annual increments, age 30, natural stands, are 56, 82, 114, and 141 cubic feet.

Plantations make up 44 percent of the slash pine ecosystem. The difference between midpoint mean annual increments for the four site index classes at age 30 are not greatly different for fully stocked plantations and natural stands. A comparison of mean annual increments of well-stocked plantations with well-stocked natural stands can be made for Schumacher and Coile (1960) data and for plantation data provided by Bennett (1970b) (table 2). The site index class for plantations is based on age 25 in contrast to age 50 for natural stands. The equivalent site index values for the different ages are given by Bennett (1971a), and these values are included in table 2.

Table 2.--Estimated mean annual increment for well-stocked, natural slash pine stands and plantations, age 30, by site index class, basal area, and selected yield tables

Site index class[1]	Site index class[2]	Basal area Schumacher and Coile[3]	Mean annual increment	
			Schumacher and Coile[3]	Bennett[4]
Age 25	Age 50	Square feet	- Cubic feet -	
50	66	108	72	70
60	77	117	94	94
70	88	129	120	128
80	98	140	150	166

1/ Height of dominant trees at age 25.
2/ Height of dominant trees at age 50 (Bennett 1971).
3/ Interpolated from table 2 (Schumacher and Coile 1960).
4/ MAI interpolated from table 1 (Bennett 1970b).

A comparison of midpoint mean annual increments for the natural stands and plantations indicates practically no differences for site index classes 66 and 77 at age 50. Above site index 77 the plantations appear to have higher mean annual increments up to about 16 cubic feet at site index 98 (fig. 5). These data suggest that higher midpoint mean annual increments should be used for the site index classes 80 to 93 and 93 to 110. However, only 2 percent of the ecosystem has site index values above 93. Also, some of the plantations used to estimate mean annual increments are soil bank plantings which apparently have higher cubic-volume yields plantings on old fields or prepared forest sites (Bennett 1972). Since the maximum difference between natural stands and plantations at age 30 for site index values from 66 to 88 is only 8 cubic feet, and this may be influenced by the one-time situation of soil bank plantings, the same midpoint mean annual increments were used for plantations as for natural stands.

Since plantations make up 44 percent of the ecosystem, a separate analysis was made for plantations in Florida, Georgia, and South Carolina. Ninety percent of the slash pine plantations are in these States.

Growth rates different from these estimates have been reported. Some exceptionally high accumulations of net primary production as timber have been reported for small areas of slash pine. Some reports of mean annual increments per acre for entire trees, inside the bark, in natural stands include 176 cubic feet at age 27 (Cooper 1955) and 133 at

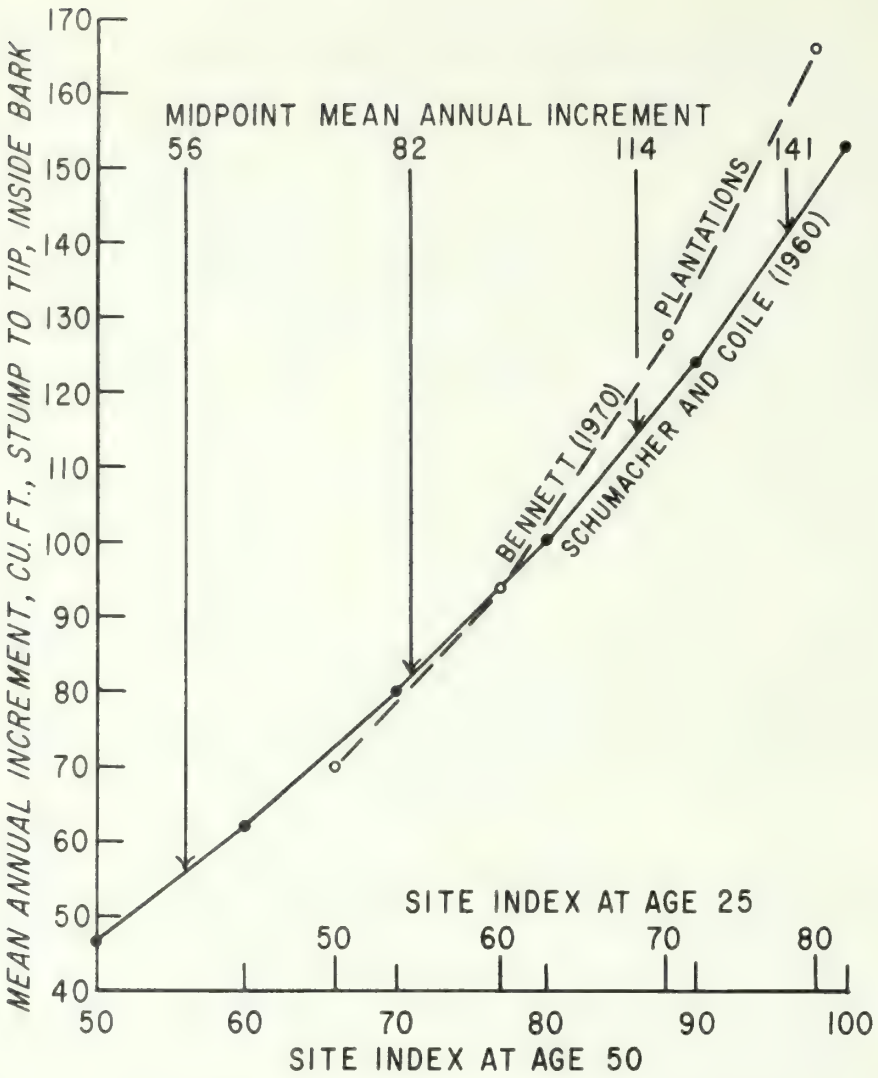

Figure 5.--The same midpoint mean annual increments, 56, 82, 114, and 141 cubic feet, are used for plantations as for natural stands.

age 23 (McCulley 1950). Most reports are for less accumulations (Walker and Wiant 1968). For plantations, some reports of mean annual increments are 160 cubic feet at age 16 (Lehocky and Lee 1954), 133 cubic feet at age 23 (McCulley 1950), and about 247 cubic feet at age 21 (Smith 1967). These growth rates for exceptional stands are considerably higher than the average periodic annual increment of 61 cubic feet reported for all pines, all sites, and all ages for the South (USDA FS 1973). Yields as high or higher than these exceptional mean annual increments can be expected to be achieved with intensive culture on some lands in the next rotation (Baker 1973; Schultz 1975). But, most timber must be produced at much lower rates of growth (Bennett 1962; Pomerey and Cooper 1956; Bennett 1971b). It is the capture of the biological potential for timber production in the entire ecosystem that is important for meeting future demands.

BIOLOGICAL POTENTIAL FOR TIMBER PRODUCTION

The biological potential is estimated to be 1,034 million cubic feet of net annual growth per year in entire boles, inside the bark, for well-stocked, natural and planted stands (table 3). This is 1.5 times larger than the Forest Survey estimate of 690 million cubic feet of periodic net annual growth of pine growing stock now in the ecosystem. The biological potential is 2.8 times the estimated annual removal of 370 million cubic feet.

If the rate of mortality for the biological potential is assumed to be the rate found in the Forest Survey, 0.3 percent of the growing-stock volume, then the biological potential for gross annual growth is 1,082 million cubic feet (table 3). For this rate of gross and net growth and for 30-year rotations, the optimum growing-stock volume would be 16.1 million cubic feet if the stands are equally distributed among all age classes (table 3).

Table 3.--The Forest Survey inventory and the biological potential for the slash pine ecosystem including plantations

Item	Forest Survey inventory	Biological potential
	Million cubic feet[1/]	
Periodic net annual growth	690	1,034
Removals	370	1,034
Mortality	26	48
Gross annual growth	716	1,082
Pine growing stock	[2/]7,639	[3/]16,104

1/ Inside bark, stump to tip.
2/ Includes associated pines but not associated hardwoods.
3/ Assumes pure slash pine stands equally distributed among all age classes to age 30.

TIMBER PRODUCTION PROVINCES

The biological potential for timber production is not uniformly distributed over the range of the ecosystem. The proportion of area in slash pine and the distribution of site index classes vary considerably in different parts of the range (tables 4 and 5). Environmental differences include

the amount of rainfall, length of growing season, major soil groups, physiography, temperature, radiation, and susceptibility to injury by insects and diseases. Racial variation occurs in survival, growth, wood characteristics, and other traits (Dorman and Squillace 1974). In some habitats pond pine is the common pine associate while in other habitats shortleaf, loblolly, or longleaf pine is the next most important pine to slash.

Table 4.--Area of commercial forest land in the range of the slash pine ecosystem and the proportions in the slash pine ecosystem by timber production province and state

Timber production province	State	Area of commercial forest land	Proportion of area in slash pine ecosystem [1]	
		- Thousand acres -		Percent
Terraces	Ga.	5,801	2,518	43.4
	Fla.	3,632	1,701	46.8
	Total	9,433	4,219	44.7
Tifton	Ga.	4,816	1,582	32.8
	Fla.	1,400	325	23.2
	Ala.	1,207	181	15.0
	Total	7,423	2,088	28.1
West Florida	Fla.	7,128	2,430	34.1
	Ala.	1,847	364	19.7
	Miss.	1,738	565	32.5
	La.	686	118	17.2
	Total	11,399	3,477	30.5
South Florida	Fla.	4,072	969	23.8
Plantation	S. C.	7,957	574	7.2
	Ga.	4,453	423	9.5
	Total	12,410	997	8.0
All provinces		44,737	11,750	26.3

[1] Includes natural stands and plantations.

Table 5.--Area of the slash pine ecosystem by timber production province and the proportion in four site index classes

Timber production province	All classes	Site index class[1/]			
		50-62	62-80	80-93	93-110
	Thousand acres	Percent			
Terraces	4,219	3	73	23	1
Tifton	2,088	2	62	34	2
West Florida	3,477	16	61	21	2
South Florida	969	29	60	11	--
Plantation	997	8	65	26	1
All provinces	11,750	9	66	23	2

[1/] Height of dominant trees at age 50; based on site index data from Schumacher and Coile (1960) and the Forest Survey.

An attempt to subdivide the ecosystem range by habitats and genotypes could result in an infinite number of categories. However, some practical although subjective subdivisions can be made on the basis of the proportion of area in slash pine, distribution of site index classes, and important physiographic features (fig. 6). It was assumed that the next generation of trees in the subdivisions would respond to natural events and grow as well as the slash pine trees that were measured on the Forest Survey plots. Thus, the biological potentials of these geographic subdivisions are based on the demonstrated growth rate of existing trees. Since the primary concern is timber production and physiographic features are a major consideration, the subdivisions of the slash pine ecosystem are called Timber Production Provinces (TIPP).

Descriptions of the geology, topography, soils, and climate for these five TIPP's are available in a number of publications (USDA 1936; Atwood 1940; Murray 1961; Hodgkins 1965; USDI, Geological Survey 1970; Buol 1973; Hunt 1974).

Within these five TIPP's 11.75 million acres of the ecosystem support 7,639 million cubic feet of growing stock (table 6). Periodic annual growth is about 9.1 percent of the growing stock, but varies from 18.5 percent in the Plantation TIPP to 7.5 percent in the South Florida TIPP. The average periodic net growth rate of 9.1 percent is larger than the estimated biological potential of 6.4 percent (1,034/16,104, table 3). The higher percentage for periodic growth is due to a large number of young stands near the age for culmination of current annual increment and the relatively low volume of growing stock--less than half that required to achieve the biological potential.

Figure 6.--Timber Production Provinces for the slash pine ecosystem.

The rates of annual removals plus mortality are less than periodic annual growth for all TIPP's (table 6). But the rate of removals should be related to potential growth for the rotation period and not to periodic growth. For these stands, the rates of removal cannot be as large as the periodic annual growth without further reducing the volume of an already small growing stock and reducing the potential production. If the maximum removal rate is taken to be the biological potential of 6.4 percent of the growing-stock volume, then the 6.6 percent value of removals in the Terraces TIPP can be expected to further reduce an already low growing-stock volume. Removal rates of 2 to 4.4 percent in the other TIPP's should provide for a slow accretion of growing stock.

Mortality from all causes, including insects, diseases, fire, and natural competition, averages 0.3 percent of the growing-stock volume. The reasons for the relatively high rate of mortality in the South Florida TIPP (1.1 percent) are unknown. Mortality is important for specific stands, but is not the most important reason for the relatively low growing-stock volumes for the entire ecosystem.

Table 6.--Growing stock and the periodic annual growth, removals, and mortality of pine as a percent of the pine growing stock for the slash pine ecosystem by timber production province

Timber production province	Growing stock	Periodic annual growth	Removals	Mortality
	Million cu. ft.	- - - - Percent - - - -		
Terraces	3,128	8.4	6.6	0.3
Tifton	1,810	8.7	3.1	.3
West Florida	1,795	8.2	4.4	.3
South Florida	385	7.5	2.0	1.1
Plantation	519	18.5	4.0	.4
All provinces	7,639	9.1	4.9	.3

Not all slash pines are included in the TIPP's. Plantations west of the Mississippi River and in North Carolina are omitted. Also, within the ecosystem range (fig. 6), some slash pines in other ecosystems are excluded because these trees are usually widely scattered and the productive potential is small relative to the defined ecosystem. The amount of slash pine growing stock excluded from the ecosystem is about 1.5 percent of the 9.0 billion cubic feet of the total growing-stock volume for the species in the South.

The biological potential varies among TIPP's by site index classes (table 7). For all TIPP's, 61 percent of the potential (632 million cubic feet) is in site index class 62 to 80 and 30 percent (315 million cubic feet) is in site index class 80 to 93. Only 6 percent of the potential is in site index class 50 to 62 and only 3 percent is in site index class 93 to 110. This latter class probably has the best economic opportunities, but 77 percent of the biological potential for slash pine timber is on land in site index classes 60 to 93 in the Terraces, Tifton, and West Florida TIPP's.

The average biological potentials per acre are about 88 cubic feet for all TIPP's (table 8). The apparent reason for this is that about two-thirds of the area for all TIPP's is in site quality classes 62 to 80. The exception is the Tifton TIPP with a higher than average potential of 93 cubic feet per acre. This TIPP also has a higher than average proportion of site indices above 80.

Table 7.--The estimated annual biological potential for the slash pine ecosystem by timber production province and site index class

Timber production province	All classes	Estimated biological potential for annual growth by site index class[1]			
		50-62	62-80	80-93	93-110
	Million cubic feet[2]				
Terraces	377.3	6.1	252.6	111.8	6.8
Tifton	194.7	3.1	105.5	79.9	6.2
West Florida	298.6	30.9	174.1	82.0	11.6
South Florida	75.4	15.8	47.3	12.3	--
Plantation	88.2	4.9	52.8	29.4	1.1
All provinces	1,034.2	60.8	632.3	315.4	25.7

1/ Height of dominant trees at age 50; based on site index data from Schumacher and Coile (1960).

2/ The midpoint mean annual increment at age 30 multiplied by the respective area in each site quality class. Volume inside bark, stump to tip.

Table 8.--The average biological potential per acre, the periodic annual increment per acre, the biological potential, the periodic annual increment, and the area of the slash pine ecosystem by timber production province

Timber production province	Average biological potential	Average periodic annual increment	Biological potential	Periodic annual increment	Area
	Cubic feet per acre[1]		Million cubic feet[1]		Thousand acres
Terraces	89	62	377.3	262.4	4,219
Tifton	93	76	194.7	157.8	2,088
West Florida	86	42	298.6	146.8	3,477
South Florida	88	30	85.4	29.1	969
Plantation	88	94	88.2	94.0	997
All provinces	88	59	1,034.2	690.1	11,750

1/ Volume inside bark, stump to tip.

The average periodic annual increments (table 8) are lower than the average biological potential for the Terraces, Tifton, West Florida, and South Florida TIPP's. This lower growth is apparently due to low stand densities as indicated by the low growing-stock volumes. In the Plantation TIPP the periodic annual increment is slightly higher than the biological potential. This is apparently caused by the large number of plantations with current annual increment near culmination (table 6) and by a removal rate below the 30-year rotation potential of 6.4 percent. From the information in table 8, it is apparent that total timber production is determined to a large extent by the amount of land area in slash pine and the amount of growing-stock volume.

About one-half of the slash pine ecosystem is owned by farmers or miscellaneous private owners (table 9). In the South Florida TIPP and in the Tifton uplands, these owners control 83 and 70 percent of the slash pine acreage, but they control only 37 percent in the West Florida and 42 percent in the Terraces TIPP's.

Forest industry owns about 43 percent of the ecosystem with most of the holdings in the Terraces and the West Florida TIPP's. National Forests contain 3 percent of the ecosystem and other public lands amount to 4 percent. It is apparent that a very large share of the slash pine timber must come from the private ownerships and that a relatively small production of slash pine timber can be expected from public lands.

Table 9.--The area of the slash pine ecosystem by timber production province and the proportion in four ownership classes

Timber production province	Area	Ownership class			
		Farmer and miscellaneous private	Forest industry	National Forest	Other public
	Thousand acres	Percent			
Terraces	4,219	42	52	2	4
Tifton	2,087	70	28	2	(1/)
West Florida	3,477	37	53	6	4
South Florida	969	83	5	3	9
Plantation	997	64	29	(1/)	7
All provinces	11,749	50	43	3	4

1/ Less than 1 percent.

PLANTATIONS

About 44 percent (5.1 million acres) of the slash pine ecosystem is planted. Most of the plantations are in the Terraces and the West Florida TIPP's (table 10). The largest proportion of the ecosystem in plantation is in the Plantations TIPP and the smallest is in the South Florida TIPP. Ninety percent of the plantations (4.7 million acres) are in Florida, Georgia, and South Carolina. Forest Survey data are available to examine these plantations in relation to the biological potential for the entire ecosystem (fig. 2).

Plantations in Florida, Georgia, and South Carolina contain 1,625 million cubic feet of growing stock (table 11). Periodic annual growth is 246 million cubic feet. Removals are 173 million cubic feet. The biological potential for the areas occupied by these plantations is estimated to be 404 million cubic feet of net annual growth per year with a growing-stock volume of about 6,324 million cubic feet. The biological potential for net annual growth is 1.6 times the inventory (404 divided by 246) or about 6.4 percent of the potential growing-stock volume. This is the same rate as for the entire ecosystem.

Table 10.--The proportion of the slash pine ecosystem in plantations by timber production province

Timber production province	Proportion in plantations	
	Thousand acres	Percent
Terraces	1,696	40
Tifton	923	44
West Florida	1,489	43
South Florida	159	16
Plantation	864	87
All provinces	5,131	44

The distribution of site index classes for the plantations (table 12) is not greatly different from that for the entire ecosystem (table 5). The most important difference is that about 74 percent of the plantations are on site index 62 to 80 compared with 66 percent for the entire ecosystem. But the percentage of plantations above site index 80 (21 percent) is not much greater than for the entire ecosystem (25 percent). Apparently, opportunities are not available for establishing most of the plantations on site index classes above 80.

Table 11.--The Forest Survey inventory and the biological potential for slash pine plantations in South Carolina, Georgia, and Florida

Item	Forest Survey inventory	Biological potential
	Million cubic feet[1/]	
Periodic annual growth	246	404
Removals	173	404
Mortality	3	13
Gross annual growth	249	417
Pine growing stock	[2/]1,625	[3/]6,324

1/ Inside bark, stump to tip.
2/ Includes associated pines but not associated hardwoods.
3/ Assumes pure slash pine stands equally distributed among all age classes to age 30.

Table 12.--Area of the slash pine plantations by timber production province and the proportion in four site index classes for Florida, Georgia, and South Carolina

Timber production province	All classes	Site index class[1/]			
		50-62	62-80	80-93	93-110
	Thousand acres	Percent			
Terraces	1,696	3	81	15	1
Tifton	808	(2/)	68	32	(2/)
West Florida	1,111	12	75	13	(2/)
South Florida	159	4	79	17	(2/)
Plantation	864	7	66	26	1
All provinces	4,638	5	74	20	1

1/ Height of dominant trees at age 50; based on site index data from Schumacher and Coile (1960).
2/ Less than 1 percent.

About 95 percent of the plantations are privately owned (table 13). Most of the farmer and miscellaneous private ownerships are in the Tifton, South Florida, and Plantation TIPP's. Forest industry ownerships are concentrated in the Terraces and the West Florida TIPP's.

About 70 percent of the biological potential for the plantations (282 million cubic feet) is on site index class 62 to 80 (table 14). Another 26 percent of the biological potential (106 million cubic feet) is on site index class 80 to 93. Apparently planting has discriminated to some extent against site index classes below 62; less than 4 percent (14 million cubic feet) of the potential is in these lowest site classes. These plantations are probably on the deep sands in the West Florida TIPP and on the Sandhills in the Plantation TIPP (Shipman 1958). The distribution of the biological potential for plantations by site index classes is thus not greatly different from that for the entire ecosystem (table 7).

Table 13.--The area of slash pine plantations by timber production province and the proportion in four ownership classes for Florida, Georgia, and South Carolina

Timber production province	Area	Ownership class			
		Farmer and miscellaneous private	Forest industry	National Forest	Other public
	Thousand acres	Percent			
Terraces	1,696	39	60	(1/)	1
Tifton	808	72	26	1	1
West Florida	1,111	36	58	2	4
South Florida	159	64	12	5	19
Plantation	864	61	32	(1/)	7
All provinces	4,638	49	46	1	4

1/ Less than 1 percent.

Removals are 10.7 percent of the growing-stock volume (table 15). This relatively high rate of removals for these young plantations, which have a relatively low growing-stock volume, can reduce maximum production of these stands. The rate of removals should be less than 6.4 percent of the growing-stock volume in order to build the growing-stock volume to the biological potential (table 11). Only in this way can the production and removal of about 400 million cubic feet per year be achieved.

Table 14.--The estimated annual biological potential for slash pine plantations by timber production province and site index class for Florida, Georgia, and South Carolina

Timber production province	All classes	Estimated biological potential for annual growth by site index class[1]			
		50-62	62-80	80-93	93-110
	Million cubic feet[2]				
Terraces	147.7	2.1	112.2	32.4	1.0
Tifton	74.3	.2	45.1	29.0	(3)
West Florida	92.3	7.6	67.8	16.9	(3)
South Florida	13.7	.4	10.3	3.0	(3)
Plantation	76.5	3.7	46.5	25.2	1.1
All provinces	404.5	14.0	281.9	106.5	2.1

1/ Height of dominant trees at age 50; based on site index data from Schumacher and Coile (1960).

2/ The midpoint mean annual increment at age 30 multiplied by the respective area in each site quality class. Volume inside bark, stump to tip.

3/ Less than 0.1 million cubic feet.

Table 15.--Growing stock and the net growth, removals, and mortality of slash pine plantations as a percent of the pine growing stock by timber production province for Florida, Georgia, and South Carolina

Timber production province	Growing stock	Net growth	Removals	Mortality
	Million cu. ft.	Percent		
Terraces	449	13.8	23.3	0.1
Tifton	505	11.9	4.3	.2
West Florida	233	16.4	13.7	.1
South Florida	29	13.1	7.3	.2
Plantation	409	19.8	3.2	.3
All provinces	1,625	15.1	10.7	.2

The rates of removal are very high in the Terraces and West Florida TIPP's (table 15). In the Terraces, the removal rate is almost four times the biological potential, and in the West Florida TIPP it is more than twice the biological potential. In South Florida the rates of removals are slightly higher than the biological potential. In the Tifton and Plantation TIPP's the rates of removal are less than the biological potential and here the growing-stock volumes should be accumulating.

The periodic annual increments per acre in the Terraces, West Florida, and South Florida TIPP's are apparently depressed by the relatively high rates of removals (table 16). In the Terraces TIPP the average biological potential per acre is about 87 cubic feet, but the average periodic annual increment is only 36. In West Florida the average biological potential per acre is 83 cubic feet per acre per year, but the average periodic annual increment is only 34. In the Plantation TIPP, where the percent removal of growing-stock volume is 3.2 percent, the average periodic annual increment is 94 cubic feet and slightly higher than the average biological potential of 88. In the Tifton TIPP, where the removal rate is 4.3 percent of the growing-stock volumes, the average periodic annual increment is 75 cubic feet per acre and may be increasing to the 92 cubic feet per acre potential.

Table 16.--The average biological potential per acre, the periodic annual increment per acre, the biological potential, the periodic annual increment, and the area of slash pine plantations by timber production province for Florida, Georgia, and South Carolina

Timber production province	Average biological potential	Average periodic annual increment	Biological potential	Periodic annual increment	Area
	Cubic feet per acre[1/]		Million cubic feet[1/]		Thousand acres
Terraces	87	36	147.7	61.9	1,696
Tifton	92	75	74.3	60.5	808
West Florida	83	34	92.3	38.3	1,111
South Florida	86	24	13.7	3.8	159
Plantation	88	94	76.5	81.2	864
All provinces	87	55	404.5	245.7	4,638

1/ Volume inside bark, stump to tip.

A comparison of rates of removals in tables 6 and 15 suggests that for some reason plantations are being harvested at higher rates than natural stands. The continual removal of growing-stock volumes at rates higher than the biological potential, 6.4 percent of the growing-stock volume, can greatly limit the capture of the biological potential of about 400 million cubic feet per acre per year (table 11). For these plantations the removal rates should be relatively low until the growing-stock volumes have increased to approximately the biological potential of about 6,300 million cubic feet for 30-year rotations.

Mortality (table 15) is not greatly different among the Timber Production Provinces. The average is 0.2 percent of the growing-stock volume for the entire ecosystem. In relation to the relatively high rate of removals, mortality has little effect on the growing-stock volumes.

LACK OF REFORESTATION LIMITS POTENTIAL

The biological potential for slash pine is 2.8 times (1,034/370, table 3) the estimated rate of removals. If the removal rate for softwoods, including slash pine, is approximately doubled by the year 2020 (USDA FS 1973; Seaton and others 1973), the biological potential for slash pine will still be 1.4 times (1,034/740) removals. Conversion of millions of acres of hardwood forest to the slash pine ecosystem apparently is not necessary and is probably more costly than assuring the natural and artificial reforestation of practically every harvested slash pine stand. Even with the current rate of losses to mortality (tables 6 and 15), it is apparent that the average rate of removals in cubic volume can be doubled in about 30 years without adding additional acres to the ecosystem. Capture of this potential will require the reforestation with slash pine of practically every harvested acre of the ecosystem.

There are reasons to question whether some plantations now in slash pine should be reforested with slash pine after harvest. For example, many slash pine plantations on the deep sands in the Plantation and West Florida TIPP's have site index values below 62 (table 12). Many plantings are on the deep sands of the Sandhills where longleaf pine was formerly the native species (Shipman 1958). Losses from ice storms and fusiform rust (Jones 1972; Van Lear and Saucier 1973; Powers, McClure, Knight, and Dutrow 1974; Powers, Matthews, and Hawes 1974) and the relatively low site index for slash pine on deep sands (Shipman 1958; McGee 1961) suggest that many of these plantations should not be reforested with slash pine. In addition, some slash pine plantations on clay soils in the Plantation TIPP may occupy sites better adapted to loblolly pine (Brightwell 1971; Cole 1975). However, 13 and 27 percent of the West Florida and Plantation TIPP's have site index values above 80. Probably these higher sites should be retained in slash pine (table 12).

Since 1930 many acres of retired croplands have been planted to slash pine. Most of these plantings have been in the Tifton TIPP which has a history of intensive agriculture and land retirement (Krause 1970). It is from plantations in the Tifton TIPP that most of the data have been accumulated on growth and yield of plantations (Bennett and others 1959; Chappelle 1962; Bennett 1970b).

During the past 30 to 40 years many slash pine stands have been harvested without adequate provision for natural and artificial reforestation. A lack of adequate reforestation after harvest is indicated by the millions of acres of oak-pine stands that are derived from cutover pine forests (Knight and Murphy 1974). More millions of acres of natural pine stands are poorly stocked because regeneration after harvest either failed or was not tried (Knight and McClure 1974).

Additional evidence for inadequate reforestation after harvest is in the Forest Survey data for Georgia. From the third and fourth Forest Surveys, data are available from remeasured plots of harvested slash pine stands (table 17). From 1961 to 1972 only 47 percent of the harvested Forest Survey plots in slash pine stands were returned by natural and artificial regeneration to slash pine. Of these stands, 30 percent were artificially regenerated to slash pine and 17 percent were naturally regenerated. Approximately 4 percent of the harvested slash pine stands were artificially regenerated to other pines. About 5 percent were permitted to naturally regenerate to oak-pine. About 44 percent were permitted to naturally regenerate to hardwoods or were not regenerated at the time of the survey. On lands owned and leased by the forest industries only 30 percent of the harvested slash pine stands were lost to oak-pine and hardwoods. On the farmer and miscellaneous private ownerships, 59 percent of the harvested stands were lost by natural conversion to oak-pine and hardwoods.

The reforestation of harvested slash pine stands on public ownership has little effect on total production of the ecosystem since only 7 percent is in public ownership. It is the reforestation of harvested stands on the 93 percent of the ecosystem in private ownership that will determine the future production of slash pine timber.

The average net natural conversion rate to nonpine ecosystems of 49 percent of the harvested slash pine stands applies only to this particular decade in Georgia. Nevertheless, one-third of the slash pine ecosystem is in Georgia and this example indicates the relatively high rates of losses that can occur without provisions for reforestation of practically every harvested slash pine stand with slash pine.

Table 17.--Forest types reforested on harvested slash pine plots in Georgia between 1961 and 1972 by ownership class

Forest type reforested	Method of reforestation	Ownership class			All ownerships
		Farmer and miscellaneous private	Forest industry and leased	Public	
		Percent			
Slash pine	Artificial	12	56	18	30
	Natural	25	8	9	17
Other pines	Artificial	4	5	0	4
	Natural	0	1	0	0
Oak-pine	Natural	7	1	9	5
Hardwoods and not regenerated	Natural	52	29	64	44
Total		100	100	100	100

DISCUSSION

Two important actions are essential to provide future supplies of slash pine timber. These actions are: (1) Delay the harvest of slash pine plantations and natural stands until about age 30 when mean annual increments for cubic volume begin to appreciably decline. (2) Reforest practically every harvested slash pine stand with slash pine.

The delay of harvest of both plantations and natural stands until age 30 or later could greatly increase the available timber supplies in the future. Mean annual increment for cubic volume culminates for some stands 4 or 5 years prior to age 30; however, loss in mean annual increment for the most frequent site index classes, 62 to 80, is only about 5 or 6 percent to age 30 (Bennett and Clutter 1968). Apparently, forces other than the desire for maximum production of timber are forcing the harvest of plantations and some natural stands before the culmination of mean annual increment for cubic volume. Such early harvests reduce the capture of the biological potential for timber production.

With adequate reforestation of harvested stands and the delay of harvest until after culmination of mean annual increment, the rate of removals can be doubled without the conversion of large areas of hardwood forests to slash pine. The present dispersion of the slash pine ecosystem among other ecosystems, mostly hardwoods, can be maintained. Such interdispersion of ecosystems can maintain the diversity of biological production for hardwood and softwood timber, scenic values, wildlife habitats, and possibly other benefits.

LITERATURE CITED

Atwood, Wallace W.
1940. The physiographic provinces of North America. 536 p. Ginn & Co., New York.

Baker, James B.
1973. Intensive cultural practices increase growth of juvenile slash pine in Florida sandhills. For. Sci. 19:197-202.

Beltz, Roy C., and Thomas W. Chappell
1973. Trends in product logging and tree utilization in Alabama. For. Prod. J. 23(8):15-16.

Bennett, Frank A.
1962. Growth and yield of planted conifers in relation to initial spacing and stocking. Proc. Soc. Am. For., p. 22-26.

Bennett, Frank A.
1970a. Variable-density yield tables for managed stands of natural slash pine. USDA For. Serv. Res. Note SE-141, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

Bennett, Frank A.
1970b. Yields and stand structural patterns for old-field plantations of slash pine. USDA For. Serv. Res. Pap. SE-60, 81 p. Southeast. For. Exp. Stn., Asheville, N.C.

Bennett, Frank A.
1971a. Equating site indices of slash pine plantations and natural stands. USDA For. Serv. Res. Note SE-167, 4 p. Southeast. For. Exp. Stn., Asheville, N.C.

Bennett, Frank A.
1971b. The role of thinning and some other problems in management of slash pine plantations. USDA For. Serv. Res. Pap. SE-86, 14 p. Southeast. For. Exp. Stn., Asheville, N.C.

Bennett, Frank A.
1972. Cubic yields for slash pine in soil bank plantings. USDA For. Serv. Res. Note SE-182, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

Bennett, Frank A., and Jerome L. Clutter
1968. Multiple-product yield estimates for unthinned slash pine plantations--pulpwood, sawtimber, gum. U.S. For. Serv. Res. Pap. SE-35, 21 p. Southeast. For. Exp. Stn., Asheville, N.C.

Bennett, F. A., C. E. McGee, and J. L. Clutter
1959. Yield of old-field slash pine plantations. USDA For. Serv. Stn. Pap. 107, 19 p. Southeast. For. Exp. Stn., Asheville, N.C.

Boyce, Stephen G.
1975. The use of bole surface in the estimation of woodland production. Philos. Trans. R. Soc. Lond., Biol. Sci. 271(911):139-148.

Brightwell, C. Sanders
1971. Comparative performance of slash and loblolly pine. Union Camp Corp. Woodlands Res. Notes 25, 3 p.

Buol, S. W., ed.
1973. Soils of the southern states and Puerto Rico. South. Coop. Ser. Bull. 174, 160 p. [Joint Reg. Publ. by Agric. Exp. Stn. of South. States and Puerto Rico Land-Grant Univ. with coop. assist. by USDA Soil Conserv. Serv.]

Chappelle, Daniel E.
1962. Value growth of pine pulpwood on the George Walton Experimental Forest. USDA For. Serv. Stn. Pap. 140, 14 p. Southeast. For. Exp. Stn., Asheville, N.C.

Cole, Donald E.
1975. Comparisons within and between populations of planted slash and loblolly pine. Ga. For. Res. Counc. Pap. 81, 12 p.

Cooper, Robert W.
1955. Slash pine maintains maximum growth after light precommercial thinning. The Unit 59:26-27.

Dorman, Keith W., and A. E. Squillace
1974. Genetics of slash pine. USDA For. Serv. Res. Pap. WO-20, 20 p. Washington, D.C.

Enghardt, Hans G., and W. F. Mann, Jr.
1972. Ten-year growth of planted slash pine after early thinnings. USDA For. Serv. Res. Pap. SO-82, 11 p. South. For. Exp. Stn., New Orleans, La.

Ford-Robertson, F. C., ed.
1971. Terminology of forest science, technology, practice and products. Soc. Am. For. Multilingual For. Terminol. Ser. 1, 349 p.

Hodgkins, Earl J.
1965. Southeastern forest habitat regions based on physiography. Auburn Univ. Agric. Exp. Stn. For. Dep. Ser. 2, 10 p.

Hunt, Charles B.
1974. Natural regions of the United States and Canada. W. H. Freeman & Co., San Francisco, 725 p.

Jones, Earle P., Jr.
1972. Fusiform rust affects planted slash pine. J. For. 70:350-352.

Knight, Herbert A., and Joe P. McClure
1974. Opportunities for increasing timber supplies in the Southeast. USDA For. Serv. Resour. Bull. SE-28, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

Knight, H. A., and Paul A. Murphy
1974. Hardwood resources on southern pine sites. For. Prod. J. 24(7):13-16.

Krause, Orville E.
1970. Cropland trends since World War II--regional changes in acreage and use. USDA Econ. Res. Serv., Agric. Econ. Rep. 177, 15 p. Washington, D.C.

Lehocky, A. A., and Randolph B. Lee
1954. South Carolina Sand Hills can grow pine timber. J. For. 52:280-281.

Little, Elbert L., Jr., and Keith W. Dorman
1952. Slash pine (Pinus elliottii), its nomenclature and varieties. J. For. 50: 918-923.

McCulley, R. D.
1950. Management of natural slash pine stands in the flatwoods of south Georgia and north Florida. USDA Circ. 845, 57 p. Washington, D.C.

McGee, Charles E.
1961. Soil site index for Georgia slash pine. USDA For. Serv. Stn. Pap. 119, 9 p. Southeast. For. Exp. Stn., Asheville, N.C.

Mann, W. F., Jr.
1971. Early yields of slash pine planted on a cutover site at various spacings. USDA For. Serv. Res. Pap. SO-69, 16 p. South. For. Exp. Stn., New Orleans, La.

Mann, W. F., Jr., and Hans G. Enghardt
1972. Growth of planted slash pine under several thinning regimes. USDA For. Serv. Res. Pap. SO-76, 10 p. South. For. Exp. Stn., New Orleans, La.

Murray, Grover E.
1961. Geology of the Atlantic and Gulf Coastal Province of North America. 692 p. Harper & Brothers, New York.

Nelson, Thomas C., and Frank A. Bennett
1965. A critical look at the normality concept. J. For. 63:107-109.

Pomeroy, Kenneth B., and Robert W. Cooper
1956. Growing slash pine. USDA Farmers Bull. 2103, 28 p.

Powers, H. R., Jr., J. P. McClure, H. A. Knight, and G. F. Dutrow
1974. Incidence and financial impact of fusiform rust in the South. J. For. 72: 398-401.

Powers, H. R., Jr., F. R. Matthews, and R. B. Hawes
1974. Volume loss resulting from fusiform rust in young plantations of slash pine. USDA For. Serv. Res. Note SE-200, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

Schultz, Robert P.
1975. Intensive culture of southern pines: maximum yields on short rotations. Iowa State J. Res. 49(3):325-337. Part 2.

Schumacher, F. X., and T. S. Coile
1960. Growth and yields of natural stands of the southern pines. 115 p. T. S. Coile, Inc., Durham, N.C.

Seaton, Fred A., Marion Clawson, Ralph Hodges, and others
1973. Report of the President's Advisory Panel on Timber and the Environment. 541 p. Washington, D.C.

Shipman, Robert D.
1958. Planting pine in the Carolina sandhills. USDA For. Serv. Stn. Pap. 96, 43 p. Southeast. For. Exp. Stn., Asheville, N.C.

Smith, Lloyd F.
1967. Effects of spacing and site on the growth and yield of planted slash pine. U.S. For. Serv. Res. Note SO-63, 4 p. South. For. Exp. Stn., New Orleans, La.

Sternitzke, Herbert S., and Thomas C. Nelson
1970. The southern pines of the United States. Econ. Bot. 24(2):142-150.

U.S. Department of Agriculture
1929. Volume, yield, and stand tables for second-growth southern pines. USDA Misc. Publ. 50, 202 p. Washington, D.C.

U.S. Department of Agriculture
1936. Atlas of American agriculture. Var. pag. Washington, D.C.

U.S. Department of Agriculture, Forest Service
1973. The outlook for timber in the United States. For. Resour. Rep. 20, 367 p. Washington, D.C.

U.S. Department of the Interior, Geological Survey
1970. The national atlas of the United States of America. 417 p. Washington, D.C.

Van Lear, David H., and Joseph R. Saucier
1973. Comparative glaze damage in adjacent stands of slash and longleaf pine. Clemson Univ. Dep. For. Res. Ser. 27, 7 p.

Walker, Laurence C., and Harry V. Wiant, Jr.
1968. Silviculture of slash pine. Stephen F. Austin State Coll. Sch. For. Bull. 16, 113 p.

Welch, Richard L.
1974. Logging residues in Florida, Georgia, and South Carolina. For. Prod. J. 24(10):30-32.

Boyce, Stephen G., Joe P. McClure, and Herbert S. Sternitzke
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The biological potential for the slash pine (Pinus elliottii Engelm.) ecosystem is estimated to be 1 billion cubic feet of net annual growth per year, entire boles, inside the bark, for well-stocked, natural stands and plantations. The average rate of removals in cubic volume can be doubled in about 30 years without adding to the ecosystem area of 11.7 million acres. To achieve this biological potential the most important actions are to assure the reforestation of every harvested slash pine stand to full stocking and delay harvesting until about age 30 when mean annual increments for cubic volume begin to appreciably decline.

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A Forest Service Research Paper SE-142 October 1975

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The loblolly pine (Pinus taeda L.) ecosystem is capable of producing an estimated 2 billion cubic feet of net annual growth per year in entire boles, inside the bark, in well-stocked, natural stands. This volume is an estimate of the biological potential for timber production on the 19.8 million acres occupied by loblolly pine east of the Mississippi River. This potential is 35 percent larger than the present net annual growth and is more than twice the estimated rate of removals. The average rate of removals in cubic volume can be doubled in about 30 years without adding additional acres to the ecosystem.

Achieving this biological potential requires reforestation to full stocking of every harvested loblolly pine stand. Without such action both the size and the production of the loblolly pine ecosystem can be expected to decline rapidly. This decline in production is expected because net retirement of southern croplands, on which loblolly pine often seeded, has apparently ceased.

In this report the loblolly pine ecosystem east of the Mississippi River is defined, and its biological potential for timber production is estimated. Important actions for capturing the biological potential are identified. The findings of the research are expected to be important for developing action and research programs that can most effectively increase timber production over large areas while maintaining forest benefits.

DEFINITION OF THE LOBLOLLY PINE ECOSYSTEM

The loblolly pine ecosystem is a collection of physical and chemical environments, trees, shrubs, small plants, animals, and people. It is defined as all commercial forest stands, natural and planted, in which pines make up half or more of the growing stock and loblolly is the predominant pine. This ecosystem has a range within which the stands occupy certain habitats, and each habitat has a biological potential for producing loblolly pine timber and other forest benefits. The loblolly pine stands are interspersed among stands belonging to other forest ecosystems. Only about 3 to 4 percent of the loblolly pine growing-stock volume is in other ecosystems.

From 1947 to 1957 the range of the loblolly pine ecosystem (fig. 1) was about the same as that indicated in a map published in 1930 (Forbes and Mattoon 1930). A recent map (fig. 2) of the five Southeastern States, based on Forest Survey plots measured from 1966 to 1972, suggests no important changes in the geographic distribution of the ecosystem. We report here our estimates of the biological potential for timber production for this apparent natural range of the ecosystem. The areas west of the Mississippi River and the relatively small areas in plantations to the north and west of the area of primary production are not considered in this report.

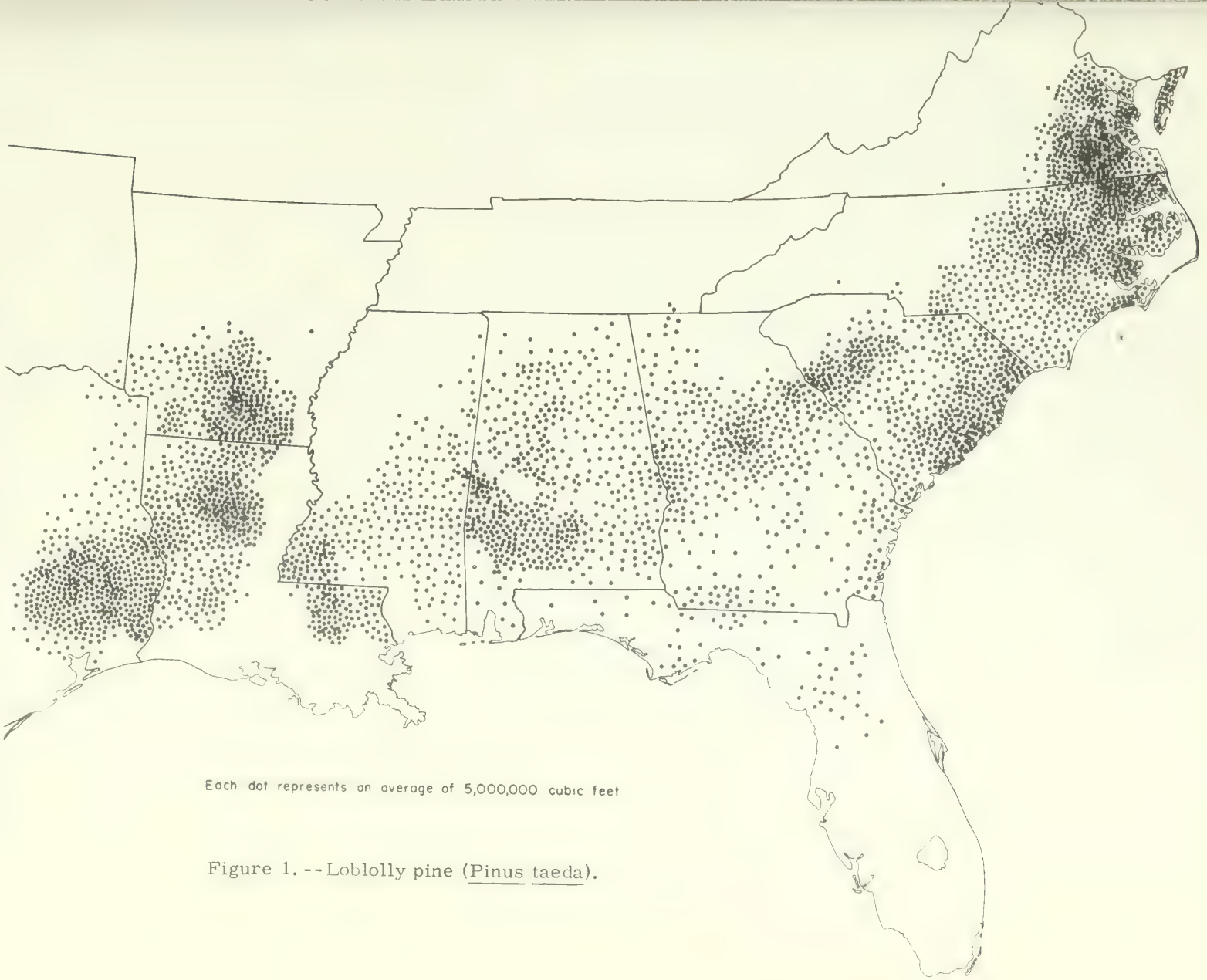

Figure 1. --Loblolly pine (Pinus taeda).

Figure 2.--A graphic representation of the loblolly pine ecosystem in five Southeastern States. Each dot represents a survey plot in a loblolly pine stand in the ecosystem.

DEFINITION OF THE BIOLOGICAL POTENTIAL FOR TIMBER PRODUCTION

Although the biological potential for timber production has been a concern of forestry for many years, it has not been formally defined in Forest Terminology (Ford-Robertson 1971). Since the concept was only recently defined in relation to total organic matter production (Boyce 1975), some explanation of the meaning is required.

The total amount of organic matter produced in a forest is the gross primary production (fig. 3). A large part of the organic matter is used by the green plants for respiration. The remainder is the net primary production that goes into wood, bark, flowers, fruits, roots, and leaves of both timber and nontimber species. Some of this material provides food and shelter for animals. Organic matter going into timber is limited by the amount of net primary production of timber species, by diversions to nontimber parts of trees, and by material eaten by animals and damaged by diseases, weather, fire, and other agents.

The accumulated fraction of net primary production expected to become timber is the biological potential for timber production. This can be stated as the amount of timber, limited only by biological constraints, that can be expected in a given time with specified silvicultural practices. This definition recognizes that timber is a fraction of ecosystem production and that silviculture can divert production of the ecosystem to or from timber, wildlife, or other segments of the system.

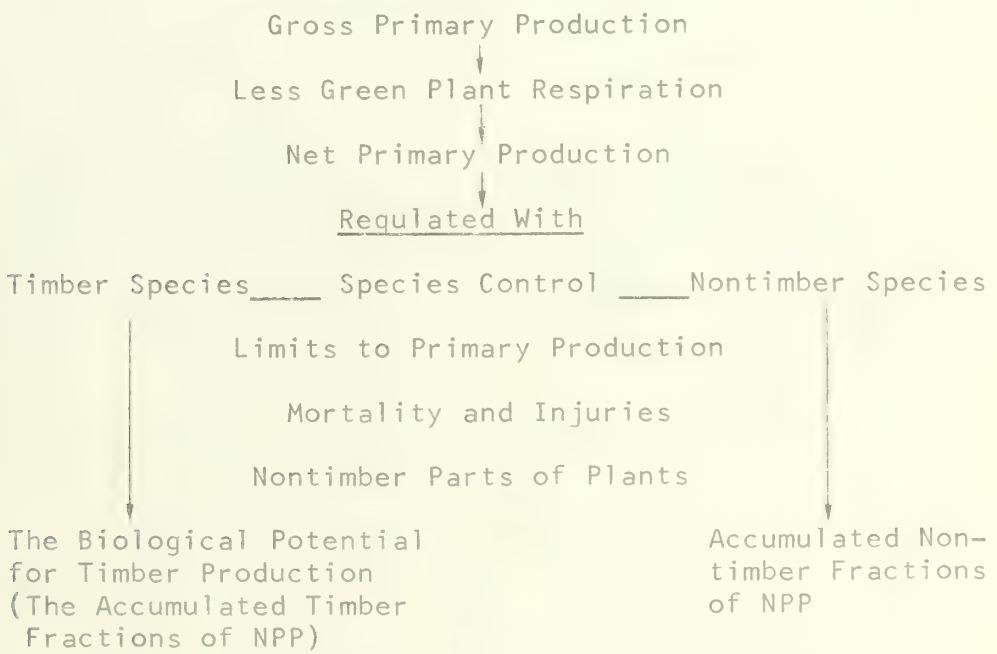

Figure 3.--The relationship of the biological potential for timber production to ecosystem production. Arrows indicate potential partitioning of organic matter.

It would be desirable to measure net primary production directly and use silviculture to divert appropriate amounts either within or among stands for timber, wildlife, and other benefits. Techniques are not available to make such measurements on millions of acres. We can, however, make some preliminary estimates of the biological potential for timber without knowing how much production is going into other parts of the ecosystem.

The question to be answered is what is the maximum amount of net primary production expected to accumulate as timber with specified silvicultural practices.

PROCEDURES

The biological potential, expressed as the annual accumulation of net primary production as timber, is estimated by multiplying the midpoint mean annual increment for each site index class by the number of acres in each site index class. This estimate is based on natural, pure, well-stocked loblolly pine stands that are assumed to be harvested and regenerated at about the age for culmination of mean annual increment. This first estimate considers only silvicultural actions required to regenerate harvested stands and maintain them in a well-stocked condition.

To carry out this procedure it is necessary to establish an age for the culmination of mean annual increment for cubic volume, a density for well-stocked stands, and expected yields for these stands. For this analysis, age 30 is used for approximate culmination of mean annual increment. The stand density and yield information is taken from the data of Schumacher and Coile (1960). The reasons for these choices are explained in the following paragraphs.

The maximum mean annual accumulation of net primary production as cubic volume of timber is expected at the age of culmination of the mean annual increment for stands maintained at the optimum stand density. For even-aged, natural stands of loblolly pine, mean annual increments for cubic volume culminate between 30 and 35 years of age (Wahlenberg 1960). For this study, age 30, the earliest age for culmination of mean annual increment, was selected as the age for estimating the biological potential.

The question of optimum stand density for maximum accumulation of net primary production as timber has never been satisfactorily answered (Nelson and Bennett 1965). For loblolly pine stands there are some usable approximations based on concepts of normally stocked (USDA 1929; MacKinney and Chaiken 1946) and well-stocked stands (Schumacher and Coile 1960). From these reports we can estimate the mean annual increments, age 30, for selected site index classes. The MAI values from Schumacher and Coile differ from those in MP-50--USDA Miscellaneous Publication 50 (1929)--by only 0 to 9 cubic feet (table 1). The values from MacKinney and Chaiken are smaller than Schumacher and Coile and MP-50 values for site index classes below 80 and are considerably larger for the higher site index classes.

Table 1.--Estimated mean annual increment for well-stocked loblolly pine stands, age 30, by site index class and selected yield tables[1/]

Site index class[2/]	USDA Misc. Publ. 50 (1929)	MacKinney and Chaiken (1946)	Schumacher and Coile (1960)	Brender and Clutter (1970)	Burkhart, Parker, Strub & Oderwald (1972)	Sullivan and Clutter (1972)	Average
	Cubic feet						
50	[3/]54	47	[3/]53	-	53	48	51
60	72	62	67	85	62	63	68
70	90	80	85	97	80	77	85
80	108	104	105	110	98	94	103
90	128	135	128	125	120	116	125
95	140	155	141	139	--	129	141
100	152	176	155	155	--	144	156
110	177	229	186	180		181	191

1/ For associated basal areas see table 2. Volumes are inside bark, stump to tip. See literature cited for references.
2/ Height of dominant trees at age 50.
3/ These increments for site index 50 were extrapolated.

In recent years, mathematical equations for estimating yield have used basal area as a measure of stand density (Brender and Clutter 1970; Burkhart and others 1972; Sullivan and Clutter 1972). It is of interest to examine the mean annual increments at age 30 from yields estimated by these equations for the site index classes and basal areas proposed for well-stocked stands (table 1). When the basal areas for well-stocked stands proposed by Schumacher and Coile (table 2) are used, the mean annual increments developed from the stand density equations do not differ greatly from those estimated from MP-50 and Schumacher and Coile data (table 1). One extreme difference of 18 cubic feet is indicated by the Brender and Clutter data for site index class 60. The Sullivan and Clutter equation provides the lowest estimates of mean annual increments for site classes 70 to 100 for the Schumacher and Coile basal areas. Although these equations for estimating yields do not provide evidence for optimum stand densities, the equations do provide another source of estimates of mean annual increments for well-stocked stands as defined by Schumacher and Coile (1960). The next procedural step is to apply one or more of these estimates of mean annual increments to the ecosystem.

Table 2.--Basal areas associated with the estimates of mean annual increment (table 1) for well-stocked loblolly pine stands, age 30, by site index class and selected yield tables[1]

Site index class[2]	USDA Misc. Publ. 50 (1929)[3]	MacKinney and Chaiken (1946)[4]	Schumacher and Coile (1960)[3]
	Square feet per acre		
50	--	126	--
60	130	139	114
70	140	146	121
80	146	151	129
90	152	156	138
95	154	158	143
100	158	160	149
110	166	165	162

1/ See literature cited for references.
2/ Height of dominant trees at age 50.
3/ Basal areas reported by the authors for well-stocked and fully-stocked stands.
4/ Basal areas were estimated from the average diameters and the numbers of trees per acre as listed in table 8 by McKinney and Chaiken for fully-stocked stands.

Extension of Estimates to the Ecosystem

The Forest Survey assigns sample plots to a site productivity class in terms of potential cubic-foot volume growth per acre at culmination of mean annual increment in fully stocked, natural stands (USDA FS 1973). Since these are nationally used classes developed for a large number of species, the midpoint values of these productivity classes are not necessarily the same as the midpoint values for individual species. The national productivity classes were not used in our study. Precision was improved by relating the site productivity classes to site index classes and determining appropriate midpoint mean annual increments for these latter classes. The national productivity classes were related to site index classes for loblolly pine as follows: 25- to 50-foot national productivity class equals site index class 50 to 60; 50- to 85-cubic-foot class equals site index class 60 to 80; 85- to 120-cubic-foot class equals site index class 80 to 95; 120- to 165-cubic-foot class equals site index class 95 to 110; and 165- to 225-cubic-foot class equals site index classes exceeding 110. Since very few loblolly pine stands have a site index larger than 110, the last two site index classes were combined to form only four site index classes for this study. For these four site index classes, the midpoint mean annual increments interpolated from Schumacher and Coile mean annual increments at age 30 (table 1) are 60, 85, 123, and 163 cubic feet per acre, for entire stems, inside the bark.

Growth rates different from these estimates have been reported. Some exceptionally high accumulations of net primary production as timber have been reported for small areas of loblolly pine forests (Ralston 1973). Mean annual increments per acre, for entire trees, inside the bark, have been reported for unusual natural stands of loblolly pine as 258 cubic feet at age 29 and 165 at age 60 (Ashe 1915). Most reports are for less accumulations (Wahlenberg 1960). For plantations, some reports of mean annual increments are 147 at age 14, 198 at age 15, 200 at age 18, and 159 at age 27 (Brightwell 1971; Watson and others 1973; Balmer and others 1975). One report of exceptional plantation growth is 288 cubic feet of merchantable stems outside the bark at 11 years of age (Langdon and others 1970). These growth rates for exceptional stands are considerably higher than the average periodic annual increment of 61 cubic feet reported for all pines, all sites, and all ages for the South (USDA FS 1973).

Yields as high or higher than these exceptional mean annual increments can be expected to be achieved with intensive culture on some lands in the next rotation (Schultz 1975). On the entire ecosystem as a whole, however, timber must be produced at lower rates of growth. It is the capture of the biological potential for timber production in the entire ecosystem that is important for meeting future timber demands. Estimates of the potential should be based on reasonable expectations for the entire ecosystem.

The midpoint mean annual increments from the Schumacher and Coile data are not greatly different from similar values for the MP-50 data or for the MacKinney and Chaiken data for the three lowest site index classes (fig. 4). Because of the general agreement of these estimates of mean annual increments, and lack of a wide difference by the yield equations (table 1), the midpoint mean annual increments from the Schumacher and Coile data were used in our analysis.

THE BIOLOGICAL POTENTIAL FOR TIMBER

The biological potential is estimated to be 2,054 million cubic feet of net annual growth per year in entire boles, inside the bark, for well-stocked, natural stands (table 3). This is 35 percent larger than the Forest Survey estimate of periodic net annual growth of pine growing stock in the ecosystem. The biological potential is more than twice the estimated annual removal of 721 million cubic feet.

If the rate of mortality for the biological potential is assumed to be the same rate found in the Forest Survey (6.9 percent of net annual growth), then the biological potential for gross annual growth is 2,195 million cubic feet. For this rate of growth and for 30-year rotations, the optimum growing-stock volume would be 34,019 million cubic feet if stands by site index classes are equally distributed among all age classes.

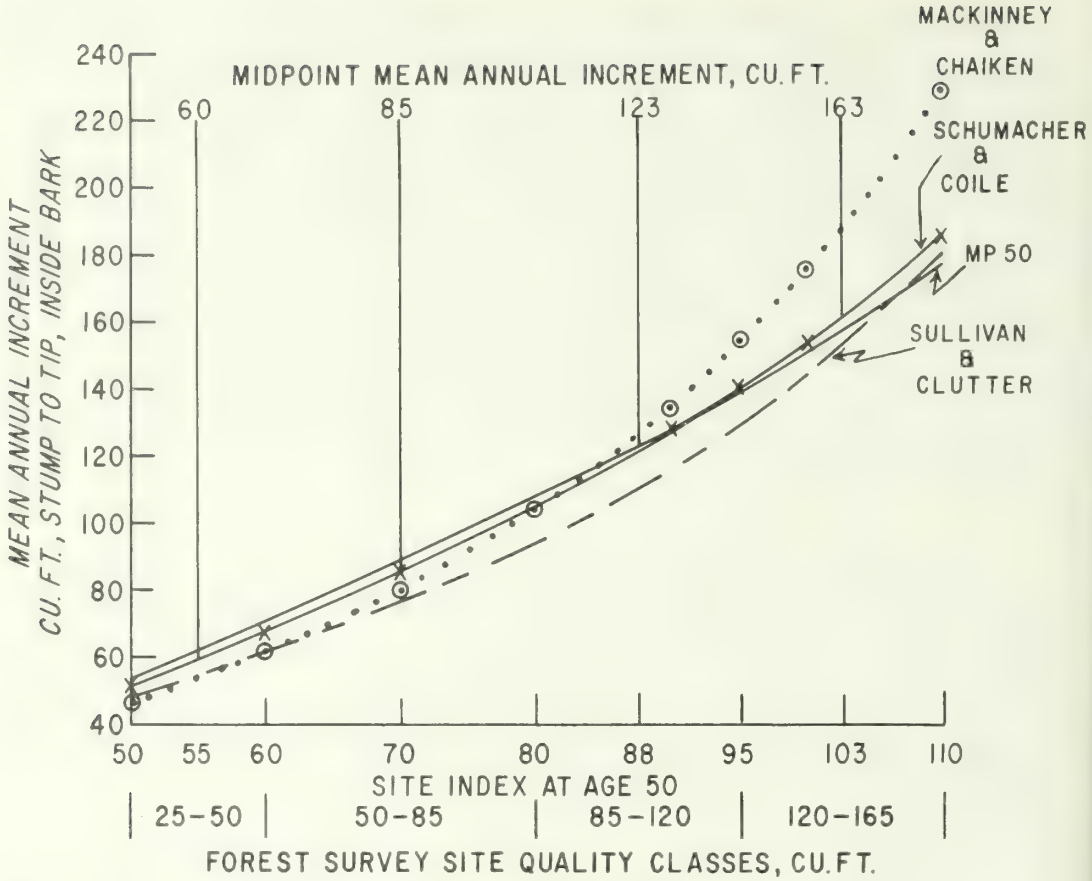

Figure 4.--For four site quality classes, the midpoint mean annual increments, age 30, are approximately 60, 85, 123, and 163 cubic feet.

Table 3.--The Forest Survey inventory and the biological potential for the loblolly pine ecosystem east of the Mississippi River

Item	Forest Survey inventory	Biological potential
	Million cubic feet	
Net annual growth	1,515	2,054
Removals	721	2,054
Mortality	104	141
Gross annual growth	1,619	2,195
Pine growing stock	1/ 21,385	2/ 34,019

1/ Includes associated pines but not associated hardwoods.
2/ Assumes pure loblolly pine stands equally distributed among all age classes to age 30.

TIMBER PRODUCTION PROVINCES

The biological potential for timber production is not uniformly distributed over the range of the ecosystem. The proportion of area in loblolly pine and the distribution of site index classes vary considerably in different parts of the range (tables 4 and 5). Differences in the environment include the amount of rainfall, length of growing season, major soil groups, physiography, temperature, radiation, and susceptibility to injury by ice, insects, and diseases. In some habitats pond pine is the common pine associate, while in other habitats shortleaf, slash, or longleaf pine is the next most important pine to loblolly. An attempt to subdivide the ecosystem range by all of these differences could result in an infinite number of categories. However, some practical although subjective subdivisions can be made on the basis of the proportion of area in loblolly pine, the distribution of site index classes, and the important physiographic features (fig. 5). Descriptions of the geology, topography, soils, and climate for these areas are available in a number of publications (USDA 1936; Atwood 1940; Murray 1961; Hodgkins 1965; USDI Geological Survey 1970; Buol 1973). Primary concern here is with identification of those physiographic areas that have different demonstrated potentials for loblolly pine timber production. We call these areas Timber Production Provinces (TIPP's).

Not all loblolly pines are included in the TIPP's. Plantations in Tennessee, Kentucky, Illinois, and Indiana are omitted because the potential production of these areas is small relative to the defined ecosystem. Also, within the ecosystem range (fig. 5), some loblolly pines in hardwood and other pine ecosystems are excluded because these trees are usually widely scattered. The amount of loblolly pine growing-stock volume outside of the defined ecosystem is estimated to be 3 to 4 percent of the 21,385 million cubic feet within the ecosystem.

The 19.8 million acres of the ecosystem support 21,385 million cubic feet of growing stock (table 6). Periodic annual growth is about 7 percent of the growing stock but varies from 4.5 percent in the Pamlico TIPP to 9.9 percent in the Blue Ridge TIPP. The average periodic growth rate of 7.1 percent is larger than the estimated biological potential of 6.0 percent (2,054/34,019, table 3). This slightly higher rate for periodic annual growth may be caused by a larger rate of periodic ingrowth into the 5-inch-diameter class than would occur for an equal distribution of ages as assumed for the biological potential. The rates of annual removals plus mortality are less than periodic annual growth for all TIPP's. The rates of periodic growth, removals, and mortality do not appear to be related to the amount of growing stock, which is indicative of the size of the TIPP's (table 4).

Table 4.--Area of commercial forest land in the range of the loblolly pine ecosystem and the proportion in the loblolly pine ecosystem by timber production province and states east of the Mississippi River

Timber production province	State	Area of commercial forest land	Proportion of area in the loblolly pine ecosystem 1/	
		- Thousand acres -		Percent
Pamlico	N. C.	3,848	800	21
Maritime	Del.	236	82	35
	Md.	541	260	48
	Va.	3,077	755	25
	N. C.	5,418	1,541	28
	S. C.	5,896	1,160	20
	Total	15,168	3,798	25
Fall Line	Va.	1,687	313	18
	N. C.	2,839	735	26
	S. C.	2,293	471	20
	Ga.	3,370	674	20
	Ala.	2,851	654	23
	Total	13,040	2,847	22
Blue Ridge	S. C.	1,669	109	6
	Ga.	575	45	8
	Total	2,244	154	7
Piedmont	S. C.	2,605	1,158	44
	Ga.	7,043	3,280	47
	Ala.	1,577	385	24
	Total	11,225	4,823	43
Gulf Coast	Ga.	10,611	616	6
	Fla.	10,434	331	3
	Ala.	4,640	618	13
	Total	25,685	1,565	6
Foothills	Ga.	1,748	394	23
	Ala.	8,905	1,701	19
	Miss.	668	77	11
	Total	11,321	2,172	19
Red Hills	Ala.	3,359	854	25
Pine Hills	La.	685	148	22
	Miss.	9,775	1,883	19
	Total	10,460	2,031	19
Mississippi	La.	1,199	352	29
	Miss.	1,617	422	26
	Total	2,816	774	27
All provinces		99,166	19,818	20

1/ Includes natural stands and plantations.

Table 5.--Proportion of the loblolly pine ecosystem in four site index classes by timber production province

Timber production province	Site index classes[1/]			
	50-60	60-80	80-95	95-110
	Percent			
Pamlico	2	36	51	11
Maritime	7	51	36	6
Fall Line	7	57	30	6
Blue Ridge	13	57	22	8
Piedmont	6	66	26	2
Gulf Coast	1	44	42	13
Foothills	5	54	33	8
Red Hills	4	24	38	34
Pine Hills	4	45	37	14
Mississippi	2	21	40	37
All provinces	5	52	34	9

1/ Height of dominant trees at age 50; based on site index data from Schumacher and Coile (1960).

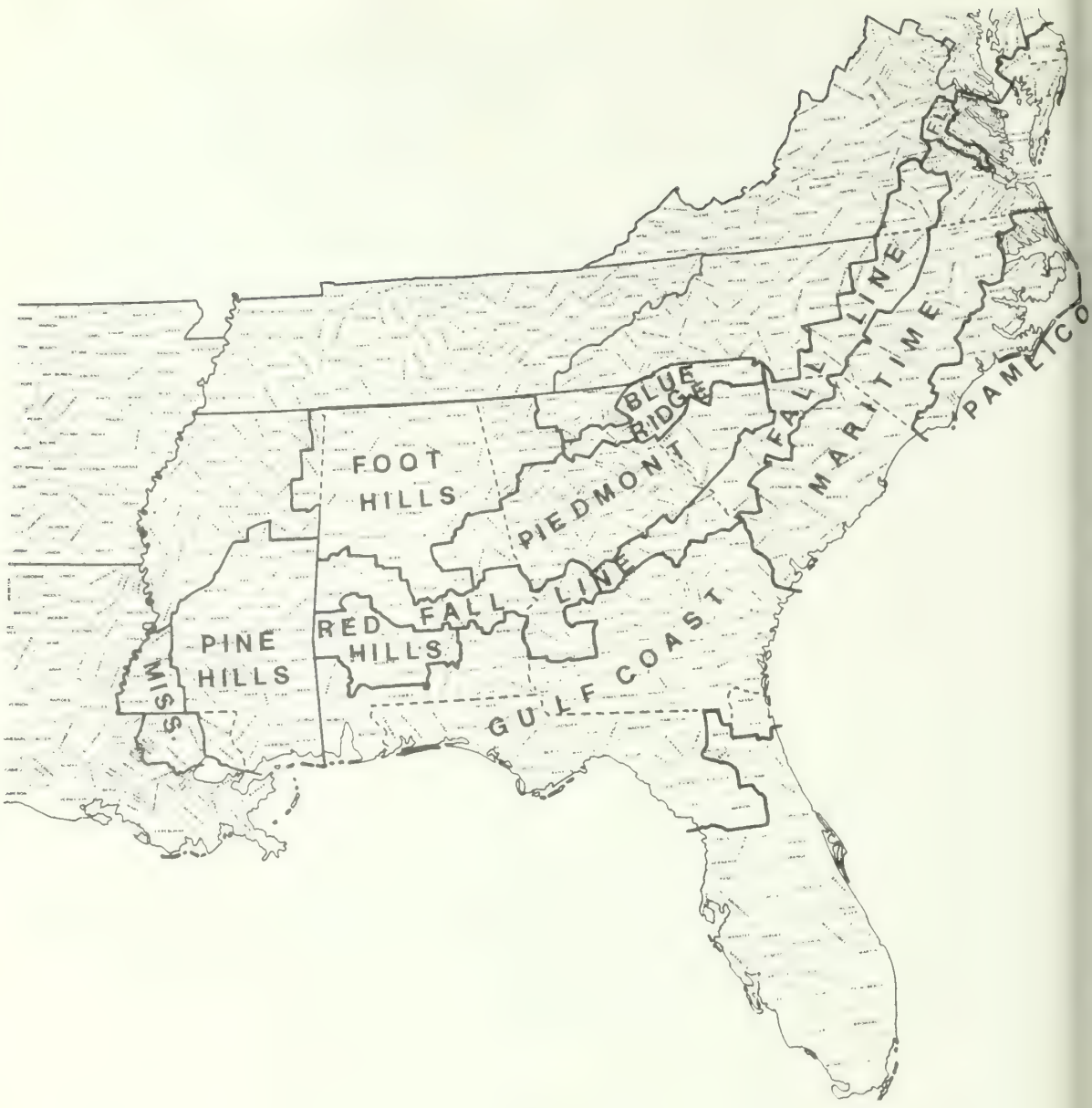

Figure 5.--Timber Production Provinces for the loblolly pine ecosystem east of the Mississippi River.

Table 6.--Growing stock and the rates of periodic annual growth, removals, and mortality of pine expressed as a percent of the pine growing stock for the loblolly pine ecosystem by timber production province

Timber production province	Growing stock	Periodic annual growth	Annual removals	Annual mortality
	Million cu. ft.[1/]	- - - - Percent - - - -		
Piedmont	4,918	8.6	3.2	0.5
Maritime	4,863	5.1	2.7	.5
Fall Line	2,784	7.5	3.7	.5
Foothills	2,264	7.8	3.8	.6
Pine Hills	1,798	8.1	4.1	.3
Gulf Coast	1,587	7.7	3.9	.5
Mississippi	1,070	7.7	3.1	.4
Red Hills	1,027	6.4	5.3	.3
Pamlico	967	4.5	1.7	.7
Blue Ridge	107	9.9	3.4	.2
All provinces	21,385	7.1	3.4	.5

1/ Volume inside bark, stump to tip.

The biological potential varies among TIPP's by site index classes (table 7). In the whole ecosystem, 43 percent of the potential, 873 million cubic feet, is in site index class 60 to 80 and 40 percent, 820 million cubic feet, is in site index class 80 to 95. Only 3 percent of the potential is in site index class 50 to 60 and only 14 percent is in site index class 95 to 110. However, in the Red Hills, Mississippi, and Pamlico TIPP's, 70 to 85 percent of the biological potential is on site index classes above 80. The average biological potentials per acre are not directly related to the average periodic annual increments of the TIPP's (table 8). The Piedmont, Maritime, and Fall Line have large biological potentials because of the large land areas. And the Mississippi, Red Hills, and Pamlico TIPP's have high average biological potentials per acre but relatively small biological potentials because of the relatively small land areas.

Table 7.--The estimated annual biological potential for the loblolly pine ecosystem by timber production province and site index class

Timber production province	All classes	Site index class[1/] 50-60	60-80	80-95	95-110
		Million cubic feet[2/]			
Piedmont	456.7	18.5	270.2	152.6	15.4
Maritime	386.1	15.2	165.5	169.0	36.4
Fall Line	282.8	12.3	137.5	104.4	28.6
Foothills	222.3	6.7	100.0	87.8	27.8
Pine Hills	221.1	5.0	77.9	92.2	46.0
Gulf Coast	173.0	.8	59.2	80.9	32.1
Red Hills	107.0	2.0	17.2	40.3	47.5
Mississippi	99.8	1.0	13.6	37.8	47.4
Pamlico	90.2	.8	24.4	50.7	14.3
Blue Ridge	14.8	1.2	7.4	4.2	2.0
All provinces	2,053.8	63.5	872.9	819.9	297.5

1/ Height of dominant trees at age 50; based on site index data from Schumacher and Coile (1960).

2/ The midpoint mean annual increment at age 30 multiplied by the respective area in each site quality class. Volume inside bark, stump to tip.

The TIPP's with the largest differences between the periodic growth and the biological potential are the Maritime, Fall Line, and Pine Hills (table 8). For well-stocked stands 20 to 30 years old, the 10-year periodic growth can be expected to be higher than the mean annual increment at age 30 (Wahlenberg 1960). It is likely that periodic growth is large relative to the biological potential in the Piedmont TIPP because large proportions of well-stocked stands are at ages near the maximum current annual increment. Relatively low periodic growth, as in the Pamlico TIPP (tables 6 and 7), could be caused by low stocking, by many stands being older than 40 years, or by a large proportion of the area being in trees less than 5 inches in diameter. The reasons for the differences in the periodic annual growth cannot be determined from the Forest Survey data. Although periodic growth is an important statistic, it is the biological potential that identifies the TIPP's with the greatest opportunities for maximum timber production (tables 7 and 8).

Table 8.--The average biological potential per acre, the periodic annual increment per acre, the biological potential, the periodic annual increment, and the area of the loblolly pine ecosystem by timber production province

Timber production province	Average biological potential	Average periodic annual increment	Biological potential	Periodic annual increment	Area
	Cubic feet per acre[1/]		Million cubic feet[1/]		Thousand acres
Mississippi	129	106	99.8	82.4	774
Red Hills	125	77	107.0	65.8	854
Pamlico	113	54	90.2	43.5	800
Gulf Coast	110	78	173.0	121.6	1,565
Pine Hills	109	72	221.1	145.6	2,031
Maritime	102	63	386.1	240.2	3,798
Foothills	102	81	222.3	176.5	2,172
Fall Line	99	73	282.8	209.1	2,847
Blue Ridge	96	67	14.8	10.4	154
Piedmont	95	87	456.7	420.5	4,823
All provinces	104	76	2,053.8	1,514.8	19,818

1/ Volume inside bark, stump to tip.

Six TIPP's, the Piedmont, Maritime, Fall Line, Foothills, Pine Hills, and Gulf Coast collectively have 85 percent of the biological potential (fig. 6). These are also the TIPP's with the largest percentage of ownership in the farmer and miscellaneous private class (table 9). The average for these owners is 72 percent of the ecosystem but increases in these six large TIPP's to 75 percent. Forest industry ownership is 22 percent of the ecosystem and increases to 30 percent in the Pamlico, Red Hills, and Mississippi TIPP's. The National Forests contain only 3 percent of the ecosystem and other public ownership is only 3 percent. It is apparent that a very large share of the timber must come from the farmer and miscellaneous private holdings and the next largest share must come from land owned or leased by forest industry. A relatively small production of loblolly pine can be expected from public land east of the Mississippi River.

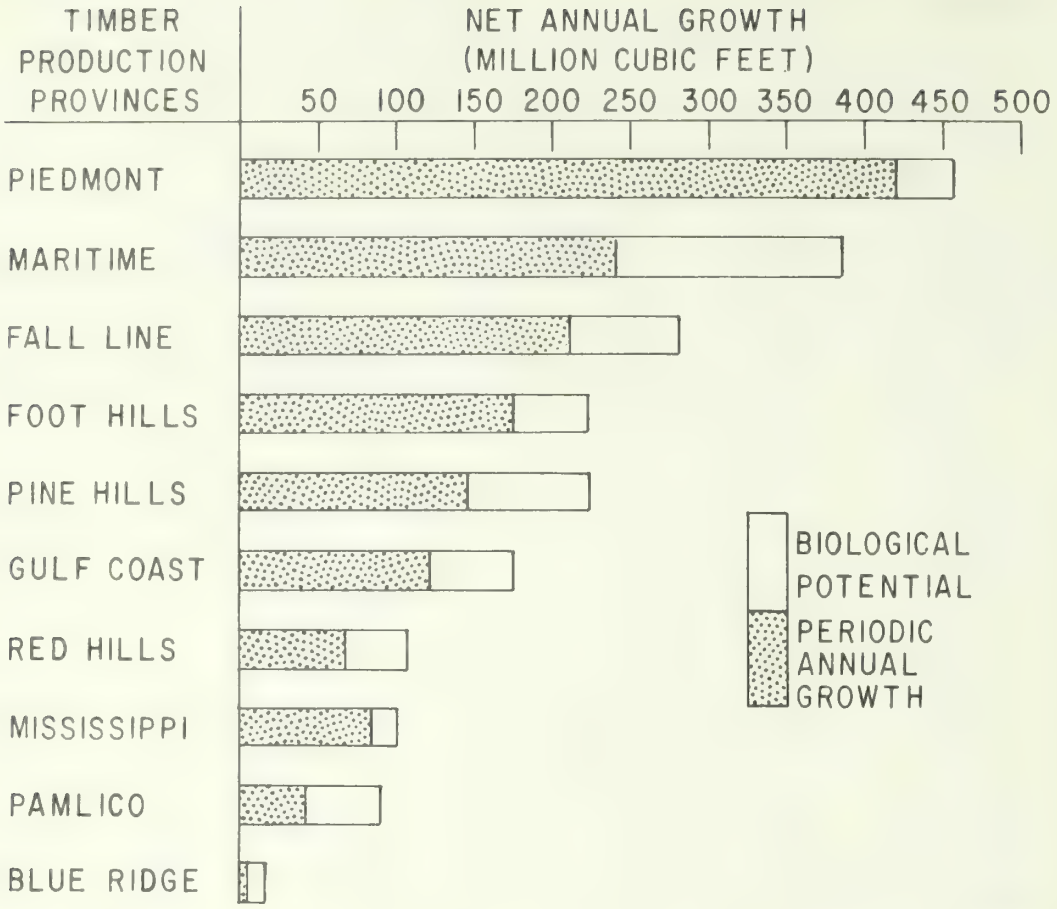

Figure 6.--The largest periodic annual growth and the largest biological potential are in the Piedmont, Maritime, and Fall Line TIPP's.

REFORESTATION AFTER HARVEST MOST IMPORTANT

The biological potential for timber is 2.8 times (2,054/721, table 3) the estimated rate of removals. If the removal rate is approximately doubled by the year 2020, as suggested by several studies (Southern Forest Resource Analysis Committee 1969; USDA FS 1973; Seaton and others 1973), the biological potential is still 1.4 times (2,054/1,442) removals. Conversion of millions of acres of hardwood ecosystems to the loblolly pine ecosystem apparently is not necessary and is probably more costly than assuring the natural or artificial reforestation of every harvested loblolly pine stand. Even with the current rate of losses to mortality (tables 3 and 6), it is apparent that the average rate of removals in cubic volume can be doubled in about 30 years without adding new areas to the ecosystem. Capture of this potential will require the reforestation with loblolly pine of every harvested acre of the ecosystem.

Table 9.--Proportion of the loblolly pine ecosystem in four ownership classes by timber production province

Timber production province	Ownership class			
	Farmer and miscellaneous private	Forest industry 1/	National Forest Systems	Other public
	Percent			
Blue Ridge	80	12	1	7
Fall Line	77	17	1	5
Piedmont	75	18	4	3
Maritime	75	21	2	2
Foothills	75	21	2	2
Gulf Coast	74	22	1	3
Pine Hills	69	19	8	4
Red Hills	66	34	--	--
Pamlico	62	30	4	4
Mississippi	54	35	10	1
All provinces	72	22	3	3

1/ Includes only industry-owned lands in Alabama, Mississippi, and Louisiana and industry-owned and leased lands in the other States.

The loblolly pine ecosystem is a byproduct of land use changes in agriculture. Only 12 percent of the ecosystem is in plantations (table 10) and most of these were established on retired croplands. A large proportion of the plantings were established on retired cropland under the Conservation Reserve Program between 1956 and 1960 (USDA 1958; Southern Forest Resource Analysis Committee 1969). For example, most of the 630,000 acres of plantations in the Piedmont TIPP are on cotton lands in Georgia and South Carolina retired after 1955. During this period farm incomes were declining as much as 25 percent per year, cropland harvested was declining about 5 percent, and practically all land going into the Conservation Reserve Program was planted to pine trees (USDA 1957; McElveen 1957). Since the termination of the Conservation Reserve Program in 1960, the annual rate of tree planting has declined to about one-half the 1959 rate.

Table 10.--The proportion of the loblolly pine ecosystem in plantations by timber production province

Timber production province	Proportion in plantations	
	Thousand acres	Percent
Piedmont	630	13
Fall Line	387	14
Foothills	375	17
Gulf Coast	265	17
Maritime	261	7
Pine Hills	178	9
Red Hills	144	17
Blue Ridge	104	68
Mississippi	51	7
Pamlico	35	4
All provinces	2,440	12

An unknown but relatively small proportion of the loblolly pine ecosystem is from natural seeding following disturbances such as fire, storms, and harvesting operations. Many of these stands are below full stocking (Knight and McClure 1974). Without cultural practices, loblolly pine rarely succeeds itself as well-stocked stands after a harvest cut. The amount of loblolly pine in post-harvested stands depends on how much of the dominant pine stand remains, how much hardwood understory remains, how much mineral soil is exposed, and how many pine seedlings are established on favorable seedbeds in the first 2 years after cutting (Wenger and Trousdell 1957). Typically, the stocking of pine is reduced with the repeated harvesting of stands that began as pure loblolly pine on retired croplands.

Most of the 72 percent of the ecosystem in farmer and miscellaneous private ownership originated from natural seeding and planting on retired cropland (Lotti and McCulley 1951). Wenger and Trousdell (1957) present excellent descriptions of natural seeding of loblolly pine on retired cropland. From early settlement there has been a rota-

tion of harvested forest lands to croplands and the retirement of croplands to the natural establishment of mostly loblolly pine within the range of the loblolly pine ecosystem. The rate of rotation was apparently fast enough to maintain some unknown but relatively large area in loblolly pine at least until about 1900 (Ashe 1915). The net amount of forest cleared for agriculture was greater than the net amount of cropland retired to forest until about 1930 (Wooten and Anderson 1957). Land used for crops in the South has continually declined since the peak about 1930 (USDA 1973).

The relatively large area in the loblolly pine ecosystem today (19.8 million acres east of the Mississippi River) is apparently due to an unusually high rate of net cropland retirement from about 1940 to 1965 (fig. 7). There were large decreases in cropland acreage in the Piedmont, Fall Line, Foothills, and Pine Hills TIPP's and lesser amounts in the other TIPP's. Only a few counties of the ecosystem had net increases in cropland acreage (fig. 8) (Krause 1970). The large net increases in south Florida and in the Mississippi Delta are outside of the loblolly pine ecosystem. The rates of net cropland retirement were very similar in Virginia, North Carolina, South Carolina, Georgia, Alabama, and Mississippi. An index of net change in these States shows a slight increase in cropland to 1940, then a rapid decline to 1965 (fig. 7). The amount of cropland harvested in these States in 1970 was only 16.4 million acres. This is less than the 18.6 million acres in these States now in the loblolly pine ecosystem (table 4).

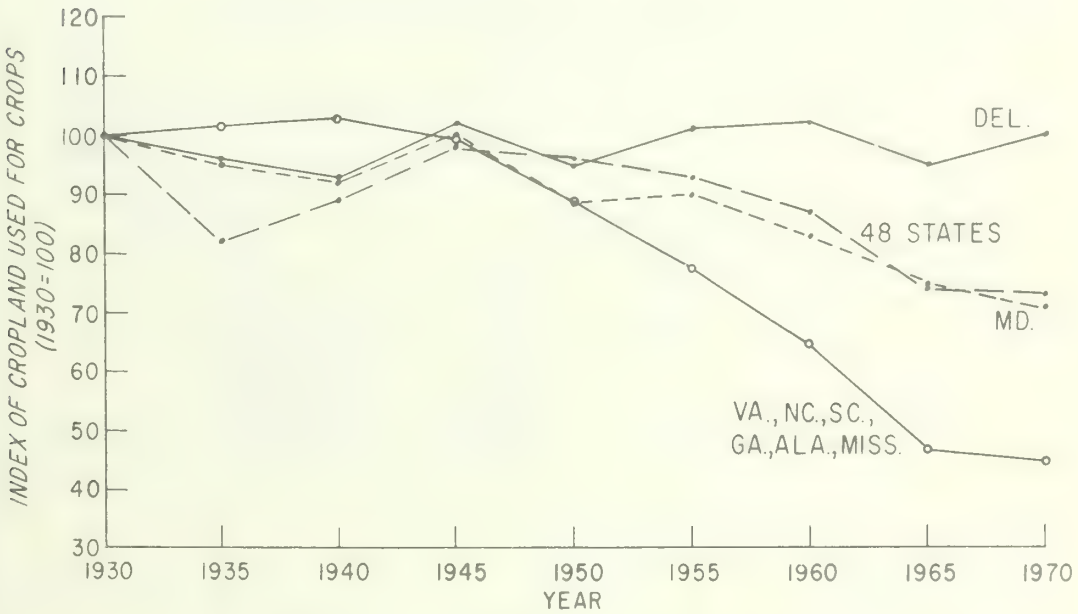

Figure 7.--The index of cropland apparently stabilized after 1965 following a rapid decline since 1940 for six important states in the loblolly pine ecosystem east of the Mississippi River (from Census of Agriculture).

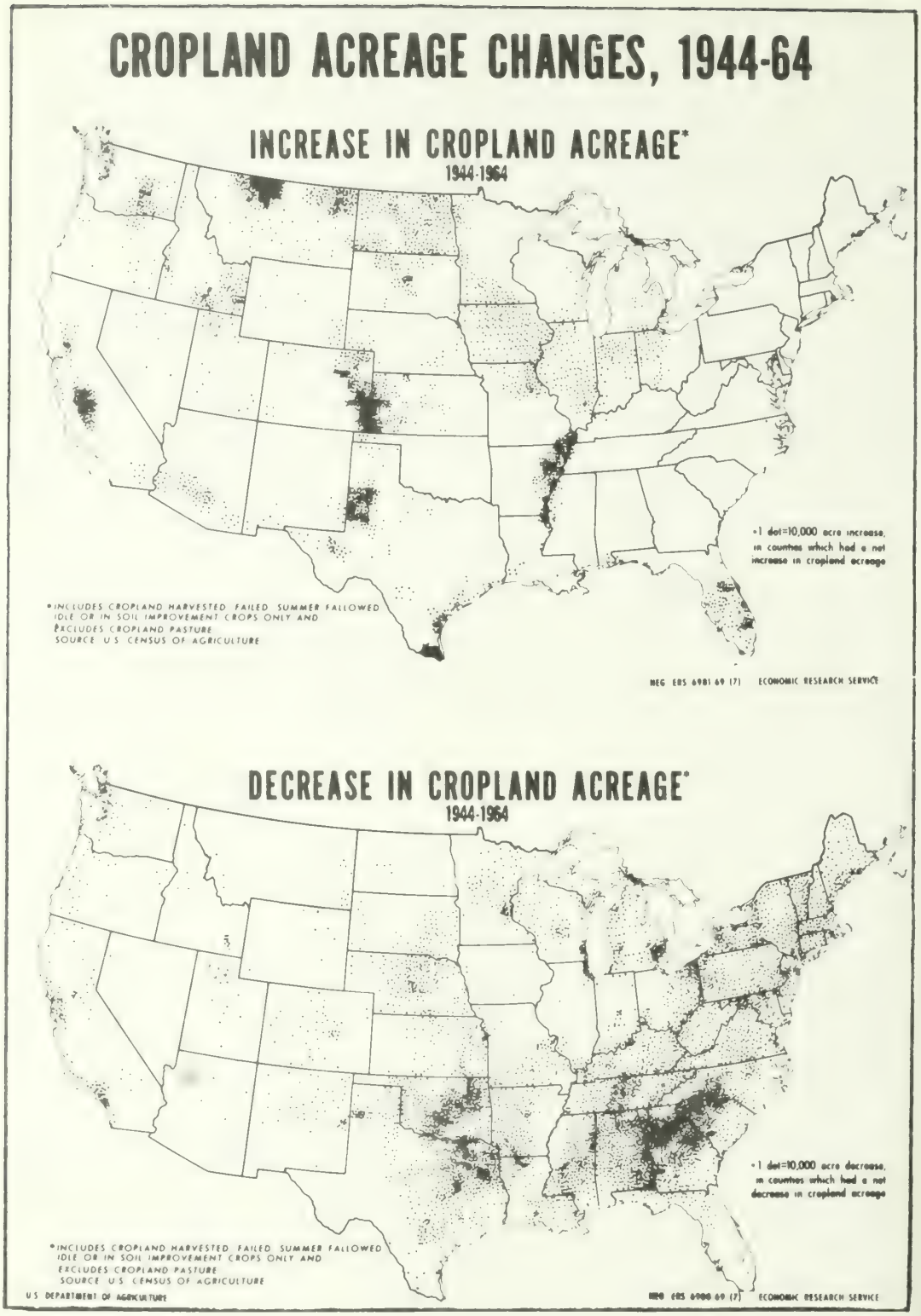
CROPLAND ACREAGE CHANGES, 1944-64
INCREASE IN CROPLAND ACREAGE*
1944-1964
•1 dot=10,000 acre increase, in counties which had a net increase in cropland acreage
*INCLUDES CROPLAND HARVESTED, FAILED, SUMMER FALLOWED, IDLE OR IN SOIL IMPROVEMENT CROPS ONLY AND EXCLUDES CROPLAND PASTURE
SOURCE: U.S. CENSUS OF AGRICULTURE
NEG. ERS 6981 69 (7) ECONOMIC RESEARCH SERVICE
DECREASE IN CROPLAND ACREAGE*
1944-1964
•1 dot=10,000 acre decrease, in counties which had a net decrease in cropland acreage
*INCLUDES CROPLAND HARVESTED, FAILED, SUMMER FALLOWED, IDLE OR IN SOIL IMPROVEMENT CROPS ONLY AND EXCLUDES CROPLAND PASTURE
SOURCE: U.S. CENSUS OF AGRICULTURE
U.S. DEPARTMENT OF AGRICULTURE
NEG. ERS 6980 69 (7) ECONOMIC RESEARCH SERVICE

Figure 8.--Cropland acreage declined from 1944-1964 in the range of the loblolly pine ecosystem at a higher rate than in many other parts of the Eastern United States. Each dot equals 10,000 acres. Adapted from Agricultural Economic Report 177.

Since about 1965 the amount of land used for crops in the South and in the 48 states has been relatively stable (USDA 1973). A continued rotation of cropland and forest can be expected, but this interchange is expected to be relatively small. The rapid rate of cropland retirement in the range of the loblolly pine ecosystem has apparently ceased or greatly slowed.

The abrupt change in the rate of cropland retirement since 1965 is expected to result in a rapid decline in the reforestation and in the production of the loblolly pine ecosystem as stands are harvested. This change occurred in Delaware where the amount of cropland harvested declined from 1930 to 1940 and has been relatively stable since 1945 (fig. 7). The first Forest Survey was in 1957 and the second in 1972. The volume of loblolly pine removed between surveys was 87 percent greater than net growth, acreage decreased 50 percent, and the growing-stock volume decreased 20 percent. Yet during this period the annual removal of growing-stock volumes declined from 8.9 to 8.1 million cubic feet (Ferguson 1959; Ferguson and Mayer 1974).

In Maryland the area of cropland declined between 1930 and 1940 and increased between 1940 and 1945 (fig. 7). In the southern and eastern shore counties in the area of the loblolly pine ecosystem, land retirement almost stopped by 1955. The continued decline in the index of cropland after 1955 (fig. 7) is primarily due to urbanization in the north central counties. Between 1950 and 1964 the volume of loblolly pine removed between surveys was 38 percent greater than net growth, acreage decreased 25 percent, and growing-stock volume decreased 20 percent (Ferguson 1967). As in Delaware, the decline in growing stock coincided with a decline in removals. Removal of growing-stock volumes of softwoods, mostly loblolly pine, declined from 32.8 to 28.1 million cubic feet.

In both of these States the decline of periodic growth to below a declining rate of removals must be attributed to a low rate of ingrowth into the 5-inch-diameter classes. Such reductions in ingrowth are due to reduced rates of reforestation of the ecosystem.

In Virginia, North Carolina, South Carolina, Georgia, Alabama, and Mississippi the unusually high rates of cropland retirement have apparently sustained the reforestation of the loblolly pine ecosystem, maintained relatively high rates of ingrowth, and resulted in an increase in net periodic growth since about 1950. With the net retirement of cropland approaching an end after 1965, declining rates of natural reforestation may be indicated by declining rates of ingrowth in the next few years. In time, reduced rates of reforestation could decrease periodic growth to below the rate of removals.

However, capture of the biological potential of 2 billion cubic feet of net annual growth per year can be achieved by reforesting every harvested loblolly pine stand and maintaining these stands in a well-stocked condition. Apparently, during the past 30 to 40 years many loblolly pine stands have been harvested without adequate provision for natural and artificial reforestation. A lack of adequate reforestation is indicated by the millions of acres of oak-pine stands which, for the most part, derived from cutover pine forests (Knight and Murphy 1974). On more millions of acres of poorly stocked natural pine stands either no provisions were made for adequate regeneration or regeneration efforts failed (Knight and McClure 1974). Additional evidence for inadequate regeneration after harvest is from the experience in Delaware and Maryland where removals exceeded growth not because of increased rates of harvest but rather from inadequate regeneration after harvest.

Both the rates of harvest and artificial regeneration in Georgia are among the highest in the South. From the third and fourth Forest Surveys, data from remeasured plots of harvested loblolly pine stands suggest the forest types reforested after harvest (table 11). From 1961 to 1972, only 36 percent of the harvested Forest Survey plots in loblolly pine stands were returned to loblolly pine. Of these stands only 6 percent were artificially regenerated to loblolly pine and 10 percent to a different pine. Most of the stands (about 54 percent) were permitted to naturally succeed to oak-pine or hardwoods, or were not regenerated. The average values for all ownerships are controlled primarily by the 72 percent of the plots that occurred in the farmer and miscellaneous private ownership class. Twenty-five percent of the plots were in the industry class and 3 percent in the public.

The average net natural conversion rate to nonpine ecosystems of 54 percent of the harvested loblolly pine stands applies only to this particular decade in Georgia. Nevertheless, this example indicates the relatively high rate of loss that can occur without provisions for reforestation of every harvested loblolly pine stand with loblolly pine.

DISCUSSION

The rapid retirement of cropland in the South from 1944 to 1965 has greatly increased both the area and the growing-stock volumes of the loblolly pine ecosystem. The productivity of the ecosystem may be at a peak unless considerable effort is made to reforest with loblolly pine and to develop the technology for inexpensively reforesting harvested stands.

Much is known about natural and artificial reforestation of loblolly pine (Wahlenberg 1960). The need is to include actions for reforestation in every harvesting operation. If the loblolly pine ecosystem is to remain a primary source of softwood timber, it is most important to find less costly ways to rapidly reforest every harvested loblolly pine stand at the time of harvest.

Table 11.--Forest types reforested on harvested loblolly pine plots in Georgia between 1961 and 1972 by ownership class

Forest type reforested	Method of reforestation	Ownership class: Farmer and miscellaneous private	Ownership class: Forest industry and leased	Ownership class: Public	All ownerships
		Percent			
Loblolly pine	Artificial	2	16	17	6
	Natural	34	20	0	30
Other pines	Artificial	4	20	0	8
	Natural	3	0	0	2
Oak-pine	Natural	12	5	50	11
Hardwoods and not regenerated	Natural	45	39	33	43
Total		100	100	100	100

In addition to reforestation of the entire ecosystem, on some areas, inexpensive ways are needed to divert more net primary production to timber, possibly with increased harvest and utilization of accumulated material, improved genotypes, addition of fertilizers, and use of other practices for intensive culture. Information is not available to estimate how much the biological potential of 2 billion cubic feet can be increased through intensive cultural practices for portions of the ecosystem. Such practices are probably more suitable and more effective in those TIPP's with the highest average biological potential per acre (table 8). High average biological potentials per acre, 113 to 129 cubic feet (table 8), occur in the Mississippi, Red Hills, and Pamlico TIPP's. Although the loblolly pine ecosystem in these TIPP's is only 12 percent of the total area (2,428/19,818, table 8), it is likely that intensive cultural practices in these TIPP's could make an unknown but significant contribution to an increased rate of removals.

With adequate reforestation of harvested stands, the rate of removals can be doubled for loblolly pine timber without the conversion of large areas of hardwood ecosystems to loblolly pine. The present dispersion of the loblolly pine ecosystem among other ecosystems, mostly hardwood, can be maintained. Such interdispersion of ecosystems can maintain diversity of biological production for hardwood and softwood timbers, scenic values, wildlife habitats, and possibly other forest benefits. Another important need is to develop the technology for assessing and for allocating net primary production both within and among ecosystems in relation to the production of different kinds of timber, wildlife habitats, and scenic values.

LITERATURE CITED

Ashe, W. W.
1915. Loblolly or North Carolina pine. N.C. Geol. & Econ. Survey Bull. 24. 176 p. [Prepared in cooperation with USDA For. Serv.]

Atwood, Wallace W.
1940. The physiographic provinces of North America. 536 p. Ginn & Co., New York.

Balmer, W. E., E. G. Owens, and J. R. Jorgensen
1975. Effects of various spacings on loblolly pine growth 15 years after planting. USDA For. Serv. Res. Note SE-211, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

Boyce, Stephen G.
1975. The use of bole surface in the estimation of woodland production. Philos. Trans. R. Soc. Lond., Biol. Sci. 271(911): 139-148.

Brender, E. V., and Jerome L. Clutter
1970. Yields of even-aged, natural stands of loblolly pine. Ga. For. Res. Counc. Rep. 23, 7 p.

Brightwell, C. Sanders, Sr.
1971. Comparative performance of slash and loblolly pine. Union Camp Corp. Woodlands Res. Notes 25, 3 p.

Buol, S. W., ed.
1973. Soils of the southern states and Puerto Rico. South. Coop. Ser. Bull. 174, 160 p. [Joint Reg. Publ. by Agric. Exp. Stn. of South. States and Puerto Rico Land-Grant Univ. with coop. assist. by USDA Soil Conserv. Serv.]

Burkhart, Harold E., Robert C. Parker, Mike R. Strub, and Richard G. Oderwald
1972. Yields of old-field loblolly pine plantations. Div. For. & Wildl. Resour., Va. Polytech. Inst. & State Univ. Publ. FWS-3-72, 51 p.

Ferguson, Roland H.
1959. The timber resources of Delaware: a report on the Forest Survey made by the U.S. Forest Service. USDA, For. Serv., 30 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Ferguson, Roland H.
1967. The timber resources of Maryland. U.S. For. Serv. Resour. Bull. NE-7, 93 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Ferguson, Roland H., and Carl E. Mayer
1974. The timber resources of Delaware. USDA For. Serv. Resour. Bull. NE-32, 42 p. Northeast. For. Exp. Stn., Upper Darby, Pa.

Forbes, R. D., and Donald Bruce
1930. Rate of growth of second-growth southern pines in full stands. USDA Circ. 124, 76 p. Washington, D.C.

Ford-Robertson, F. C., ed.
1971. Terminology of forest science, technology, practice and products. Soc. Am. For. Multilingual For. Terminol. Ser. 1, 349 p.

Hodgkins, Earl J.
1965. Southeastern forest habitat regions based on physiography. Auburn Univ. Agric. Exp. Stn. For. Dep. Ser. 2. 10 p.

Knight, Herbert A., and Joe P. McClure
1974. Opportunities for increasing timber supplies in the Southeast. USDA For. Serv. Resour. Bull. SE-28, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

Knight, H. A., and Paul A. Murphy
1974. Hardwood resources on southern pine sites. For. Prod. J. 24(7):13-16.

Krause, Orville
1970. Cropland trends since World War II--regional changes in acreage and use. USDA Econ. Res. Serv. Agric. Econ. Rep. 177, 15 p.

Langdon, O. Gordon, Glyndon E. Hatchell, and William P. LeGrande
1970. Loblolly pine growth topped! South. Lumberman 221(2752):126-127.

Lotti, Thomas, and R. D. McCulley
1951. Loblolly pine--maintaining this species as a subclimax in the Southeastern United States. UNASYLVA V(3):1-8.

MacKinney, A. L., and L. E. Chaiken
1946. Volume, yield, and growth of loblolly pine in the mid-Atlantic coastal region. Progress report on pulpwood stands. USDA For. Serv., Tech. Note 33,(rev.) 58 p. Southeast. For. Exp. Stn., Asheville, N.C.

McElveen, Jackson V.
1957. Family farms in a changing economy. USDA Agric. Res. Serv., Agric. Inf. Bull. 171, 94 p.

Murray, Grover E.
1961. Geology of the Atlantic and Gulf Coastal Province of North America. 692 p. Harper & Brothers, New York.

Nelson, Thomas C., and Frank A. Bennett
1965. A critical look at the normality concept. J. For. 63:107-109.

Ralston, C. W.
1973. Annual primary productivity in a loblolly pine plantation. Univ. Maine, Orono. 531 p. [Papers presented during meetings of S4.01 in Nancy, France, June 25-29, 1973, and Vancouver, B.C., Canada, Aug. 20-24, 1973.]

Schultz, Robert P.
1975. Intensive culture of southern pines: maximum yields on short rotations. Iowa State J. Res. 49(3):325-337. Part 2.

Schumacher, F. X., and T. S. Coile
1960. Growth and yields of natural stands of the southern pines. 115 p. T. S. Coile, Inc., Durham, N.C.

Seaton, Fred A., Marion Clawson, Ralph Hodges, and others
1973. Report of the President's Advisory Panel on Timber and the Environment. 541 p. Washington, D.C.

Southern Forest Resource Analysis Committee
1969. The South's third forest--how it can meet future demands. A report of the South. For. Resour. Analysis Comm., 1969, 111 p.

Sullivan, Alfred D., and Jerome L. Clutter
1972. A simultaneous growth and yield model for loblolly pine. For. Sci. 18:76-86.

U.S. Department of Agriculture
1929. Volume, yield, and stand tables for second-growth southern pines. USDA Misc. Publ. 50, 202 p. Washington, D.C.

U.S. Department of Agriculture
1936. Atlas of American agriculture. Var. pag. Washington, D.C.

U.S. Department of Agriculture
1957. Farm costs and returns, 1956 (with comparisons)--commercial family-operated farms by type and location. USDA Agric. Res. Serv., Agric. Inf. Bull. 176, 66 p.

U. S. Department of Agriculture
1958. The conversion reserve program of the soil bank--effects in selected areas, 1957. USDA Agric. Res. Serv., Agric. Inf. Bull. 185, 34 p. Washington, D.C.

U.S. Department of Agriculture
1973. Changes in farm production and efficiency: a summary report. USDA Econ. Res. Serv. Stat. Bull. 233, 31 p. Washington, D.C.

U.S. Department of Agriculture, Forest Service
1973. The outlook for timber in the United States. For. Resour. Rep. 20, 367 p. Washington, D.C.

U. S. Department of the Interior, Geological Survey
1970. The national atlas of the United States of America. 417 p. Washington, D.C.

Wahlenberg, W. G.
1960. Loblolly pine. Duke Univ. Sch. For., Durham, N.C. 603 p.

Watson, W. J., G. I. Garin, and W. B. Devall
1973. Growth of four pine species in Wilcox County, Alabama. Auburn Univ. Agric. Exp. Stn. Prog. Rep. Ser. 104, 1 p.

Wenger, Karl F., and Kenneth B. Trousdell
1957. Natural regeneration of loblolly pine in the South Atlantic Coastal Plain. USDA For. Serv. Prod. Res. Rep. 13, 78 p.

Wooten, Hugh H., and James R. Anderson
1975. Major uses of land in the United States--summary for 1957. USDA Agric. Res. Serv., Agric. Inf. Bull. 168, 102 p.

Boyce, Stephen G., Joe P. McClure, and Herbert S. Sternitzke
1975. Biological potential for the loblolly pine ecosystem east of the Mississippi River. USDA For. Serv. Res. Pap. SE-142, 27 p. Southeast. For. Exp. Stn., Asheville, N.C.

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Forest Service Research Paper SE-143 December 1975

Planting Dates for Longleaf, Slash, and Sand Pine Seeds in the Southeastern Sandhills: Effect of Temperature and Rainfall

by

Russell M. Burns

and

Robert D. McReynolds

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Southeastern Forest Experiment Station
Asheville, North Carolina

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by

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Naval Stores and Timber Production Laboratory
Olustee, Florida

The sandhills of the Southeast comprise millions of acres extending southward in a narrow band from Virginia to Florida. Much of this area presently supports unmerchantable scrub hardwoods and wiregrass. However, the sandhills have the potential for producing millions of tons of pine pulpwood and related products annually. Although conversion of this area to merchantable pines has consisted mainly of planting nursery-grown seedlings on prepared sites, direct seeding is more rapid and less expensive. Because it results in a uniformly distributed root system, seeding in the sandhills may also produce trees that grow as fast as or faster than those from nursery stock (5).

This paper reports the results of year-round seedings of pines in the sandhills of northwest Florida. Although spring and summer appeared to be ideal times for direct seeding, all of the spring and summer seedings failed. Temperature proved to be the determining factor on when to seed. Seedling establishment was best when daily high temperatures averaged no more than 71° F (22° C) and daily lows no less than 38° F (3° C) during the 10 weeks after seeding. On the basis of these results, methods are outlined on pages 12 through 16 for determining the best time to seed pines on other sandhill areas where local guidelines are lacking.

METHODS

For 2 years, longleaf pine (Pinus palustris Mill.), slash pine (P. elliottii Engelm.), Ocala sand pine (P. clausa var. clausa Ward), and Choctawhatchee sand pine (P. clausa var. immuginata Ward) were spot-seeded at biweekly intervals on a typical sandhill site on the Chipola Experimental Forest in northwest Florida. The site was adjacent to both a young pine plantation and a stand of scrub hardwoods. The soil was Lakeland sand, a siliceous, thermic, coated, typic quartzipsamment. Standing scrub vegetation was destroyed with an 11-ton (10 metric ton) double brush cutter (chopper) and a heavy-duty disk harrow.

Results were analyzed separately by year and by pine. The design was a randomized complete block with three replications. Each block contained 26 plots In each block, a different plot was seeded every 2 weeks throughout 1966. The procedure was repeated on another set of three blocks during 1967. No inter- or intra- specific comparisons were made among the four pines.

Two seed spots were established on each plot. One was protected from small mammals and birds with a cone of ¼-inch (6-mm) hardware cloth; the other was unprotected. Seeds on both spots were mechanically spaced with grids (fig. 1) and covered with one-fourth inch (6 mm) of soil. The protected spot contained 37 seeds and the unprotected spot 100 seeds.

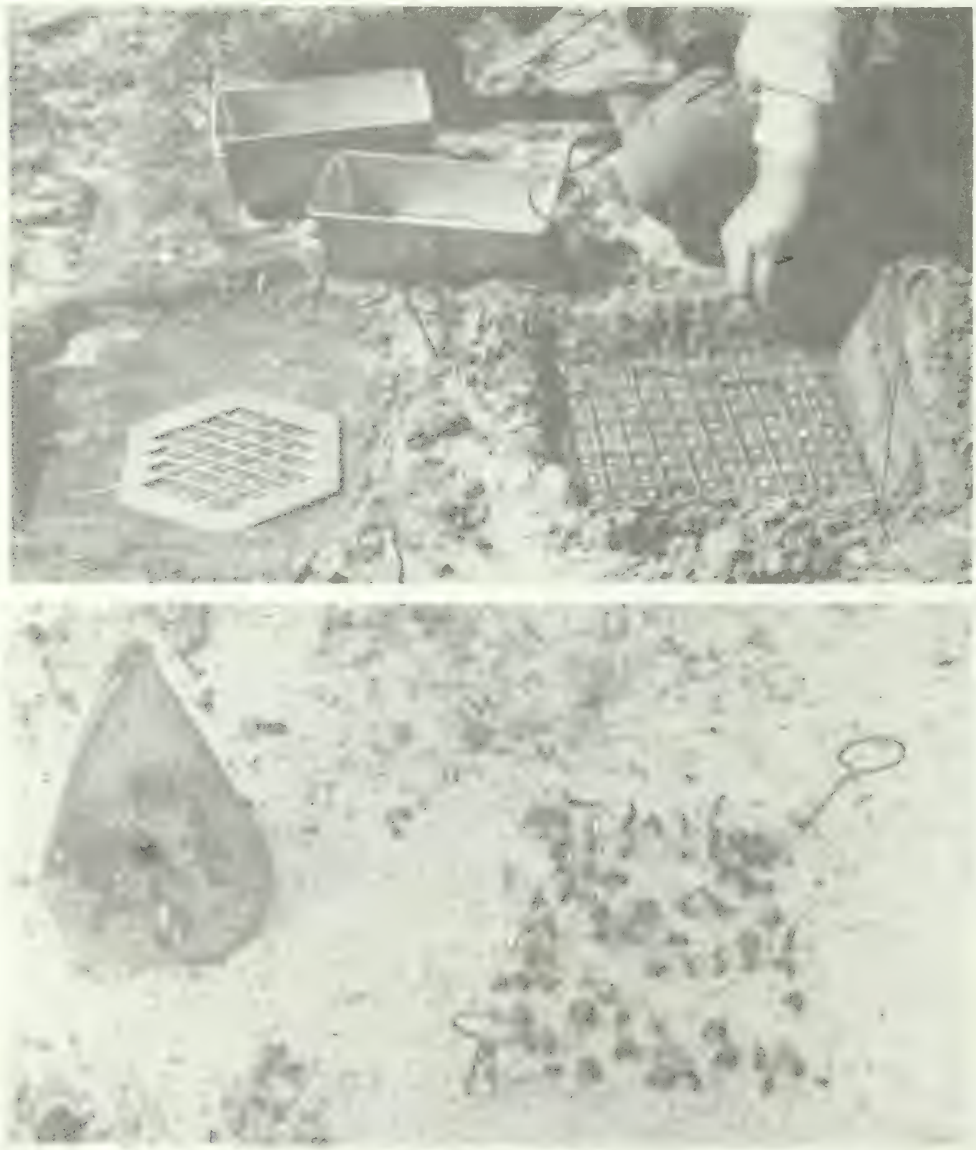

Figure 1.--Top: Placement of repellent-treated slash pine seeds on a protected (left) and an unprotected (right) seed spot. All seeds were covered with one-fourth inch (6 mm) of soil; then a mesh cone was secured over the smaller spot with wire pins. Bottom: Germination is well advanced on this longleaf pine plot. No evidence of predation of seeds or seedlings is apparent.

All seeds were from Florida, and all were from single lots except those of Choctawhatchee sand pine, which were a composite from two collections. Because Ocala sand pine has serotinous cones that retain viable seeds for several years, single collections for this species usually include cones that have matured during the current and the previous year, as was probably the case here.

The potential germinability of all seeds was determined by cutting tests. Slash and sand pine seeds were dewinged and winnowed until the tests showed that at least 95 percent of them were filled and apparently viable. Longleaf pine seeds were winnowed with wing stubs attached; to remove them before storage would lower their germinability. It proved impractical to winnow these winged seeds beyond 73 percent filled. Because it is extremely unlikely that pine seeds used for direct seeding would be winnowed more thoroughly than was done here, all seeds planted in this study were considered sound and capable of germination.

Seeds of each pine were divided into 54 numbered packets of approximately 500 each and stored at 20° F (-7° C) until used. One packet of unstratified seeds of each pine was planted every 2 weeks in 1966 and 1967. Wing stubs were removed from the longleaf pine seeds at this time, and all seeds were coated just before planting with a formulation to repel seed predators. The two extra packets of seeds were used for germination tests in the laboratory at the beginning and end of the 2-year storage period.

Counts of germinated seeds and seedlings were made on each seed spot 4, 6, 8, 10, 12, and 52 weeks after planting; and tree percentages were computed:

$$\text{Tree percentage} = \frac{\text{Number of live seedlings}}{\text{Number of seeds planted}} \times 100$$

Data from each count were subjected to appropriate statistical analyses. Activity of predators was noted whenever seeds were planted or seedlings were counted. Sample counts of sound, ungerminated seeds were made at the conclusion of the study.

Rainfall was recorded at the planting site. Air temperature was recorded at the Chipola Experimental Forest Headquarters approximately 2-½ miles (4.0 km) east of the plantings.

RESULTS AND DISCUSSION

Seedling Establishment

Spring and summer seedings failed. Some seeds planted during these seasons germinated, but few survived long enough to become established. The pattern was similar for all four pines (figs. 2-5). Seedling establishment was lowest when seeds were planted in spring and early summer, intermediate when they were planted in late summer and early fall, and highest when they were planted in late fall through midwinter.

The broken lines in figures 2 through 5 depict the proportions of seedlings established from seeds coated with repellents but not otherwise protected from birds and small mammals. These results approximate those that might be expected under operational conditions. The solid lines in these figures depict results obtained when the repellent-coated seeds were planted and protected with a mesh cone against birds and small mammals. The magnitude of differences between discrete points on the solid and broken lines roughly approximates losses to these predators.

Longleaf Pine

Many of the longleaf pine seeds planted during summer, fall, and winter germinated, but a relatively high proportion fell victim to birds and small mammals (fig. 2). Germination was lowest during the spring. In 1966, the most successful plantings were made during January and February and from mid-September through December; in 1967, they were made in January, October, November, and December. Operationally, the best time to direct seed longleaf pine in the sandhills of northwest Florida appears to be during the fall and early winter--specifically, from October 1 through January 31.

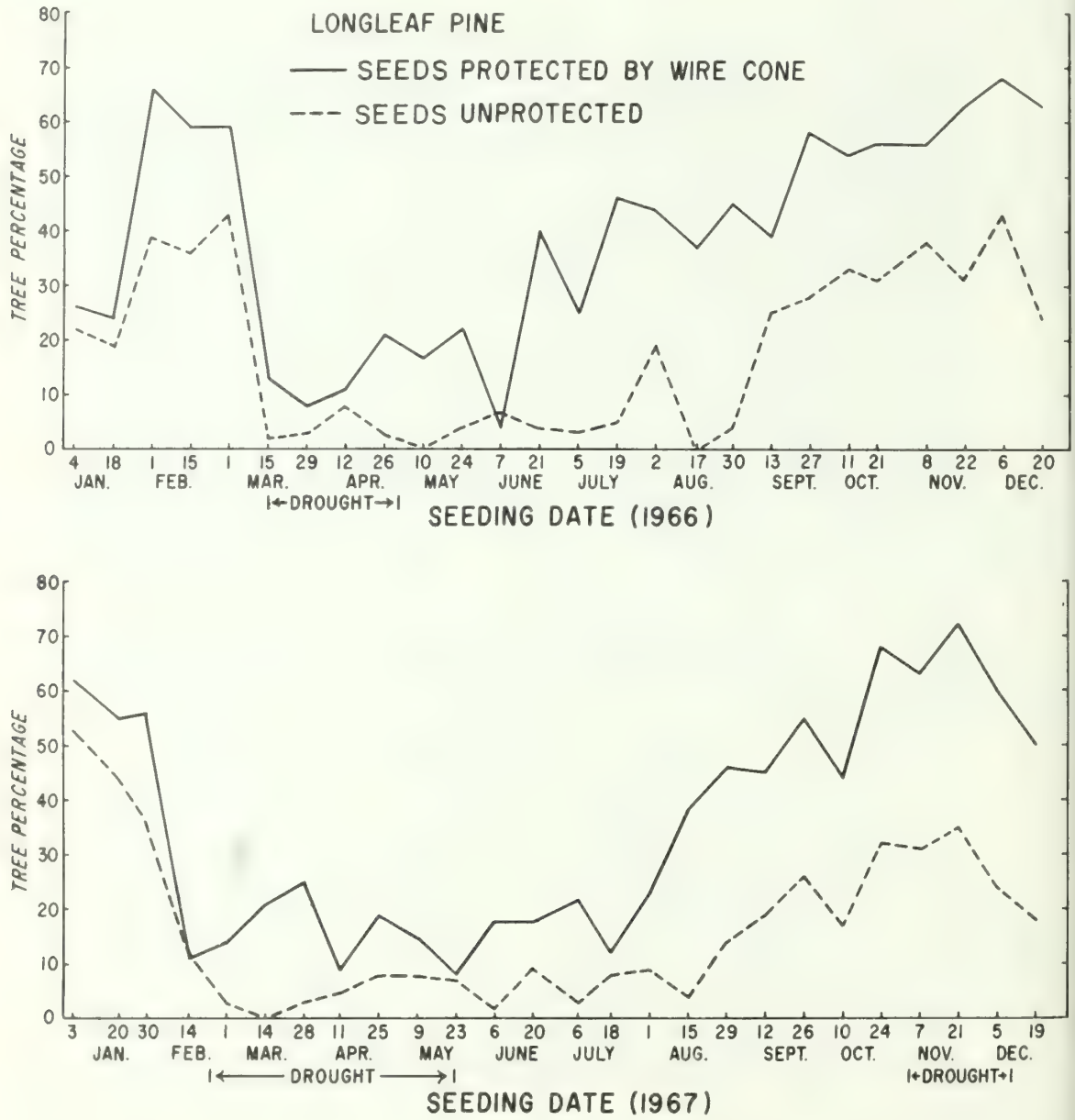
LONGLEAF PINE
SEEDS PROTECTED BY WIRE CONE
SEEDS UNPROTECTED
TREE PERCENTAGE
0 10 20 30 40 50 60 70 80
4 18 1 15 1 15 29 12 26 10 24 7 21 5 19 2 17 30 13 27 11 21 8 22 6 20
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
DROUGHT
SEEDING DATE (1966)
TREE PERCENTAGE
0 10 20 30 40 50 60 70 80
3 20 30 14 1 14 28 11 25 9 23 6 20 6 18 1 15 29 12 26 10 24 7 21 5 19
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
DROUGHT
DROUGHT
SEEDING DATE (1967)

Figure 2.--Tree percentages on protected and unprotected seed spots 52 weeks after the 1966 and 1967 plantings of longleaf pine.

Slash Pine

The seasonal pattern of seedling establishment was poorly defined for slash pine (fig. 3). Results were erratic. The two characteristic peaks during cold weather and the decline during warm weather were evident in 1966. However, in 1967, plantings in January, February, and early March produced fewer seedlings than most of those in spring and summer. Slash pine is not recommended for droughty, infertile, sandhill sites (2). However, the data suggest that, on less refractory sites in northwest Florida, direct seeding of slash pine has the highest probability of success if done in October, November, or December.

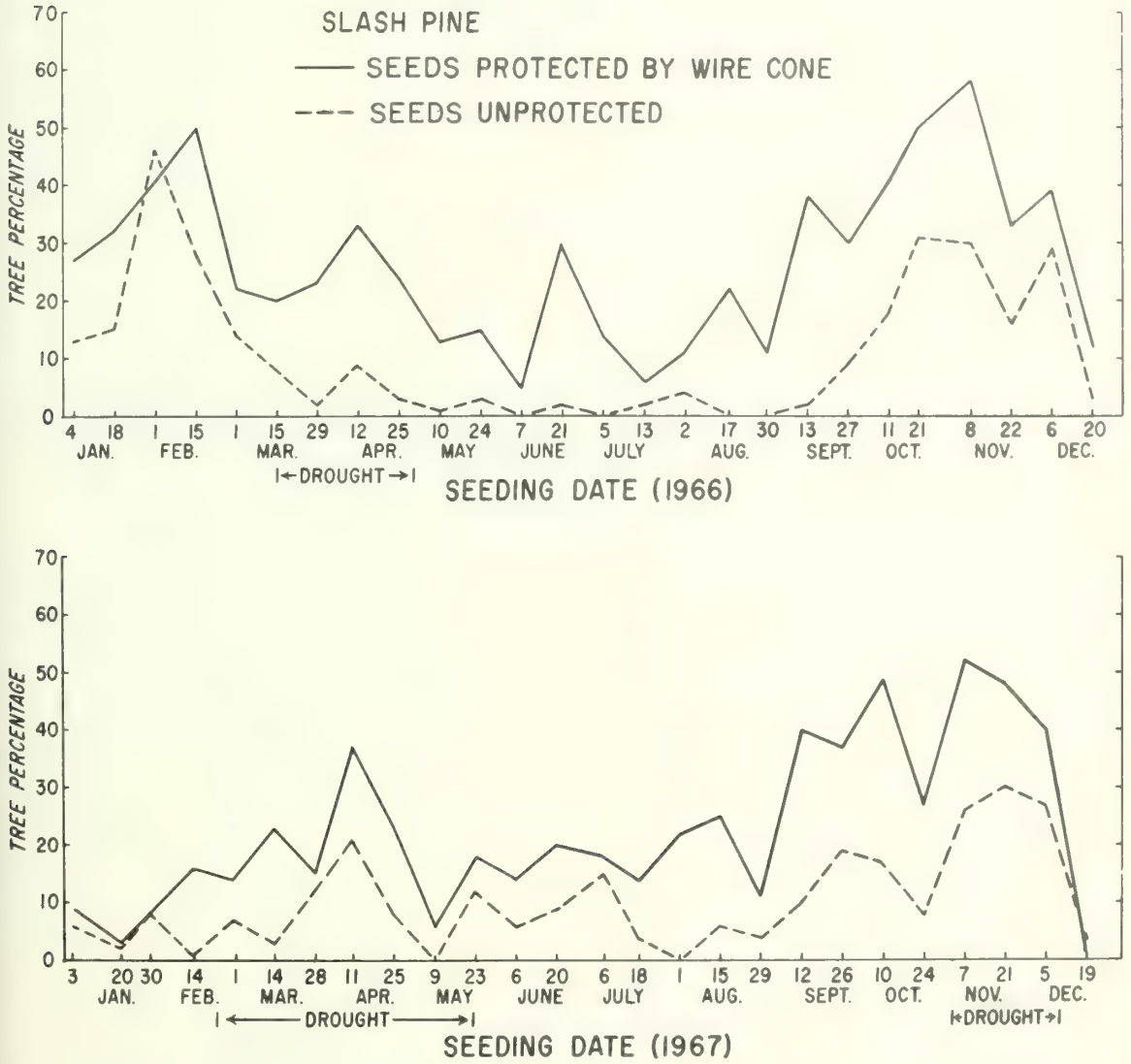
SLASH PINE
SEEDS PROTECTED BY WIRE CONE
SEEDS UNPROTECTED
TREE PERCENTAGE
0 10 20 30 40 50 60 70
4 18 1 15 1 15 29 12 25 10 24 7 21 5 13 2 17 30 13 27 11 21 8 22 6 20
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
I←DROUGHT→I
SEEDING DATE (1966)
TREE PERCENTAGE
0 10 20 30 40 50 60 70
3 20 30 14 1 14 28 11 25 9 23 6 20 6 18 1 15 29 12 26 10 24 7 21 5 19
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
I ←——— DROUGHT ———→I
I←DROUGHT→I
SEEDING DATE (1967)

Figure 3.--Tree percentages on protected and unprotected seed spots 52 weeks after the 1966 and 1967 plantings of slash pine.

Ocala Sand Pine

Few of the Ocala sand pine seeds planted on unprotected spots during the spring and summer produced seedlings (fig. 4). Predators apparently accounted for most of those that did germinate. The data indicate that direct seeding of Ocala sand pine in northwest Florida has the highest probability of success if done between November 1 and January 31.

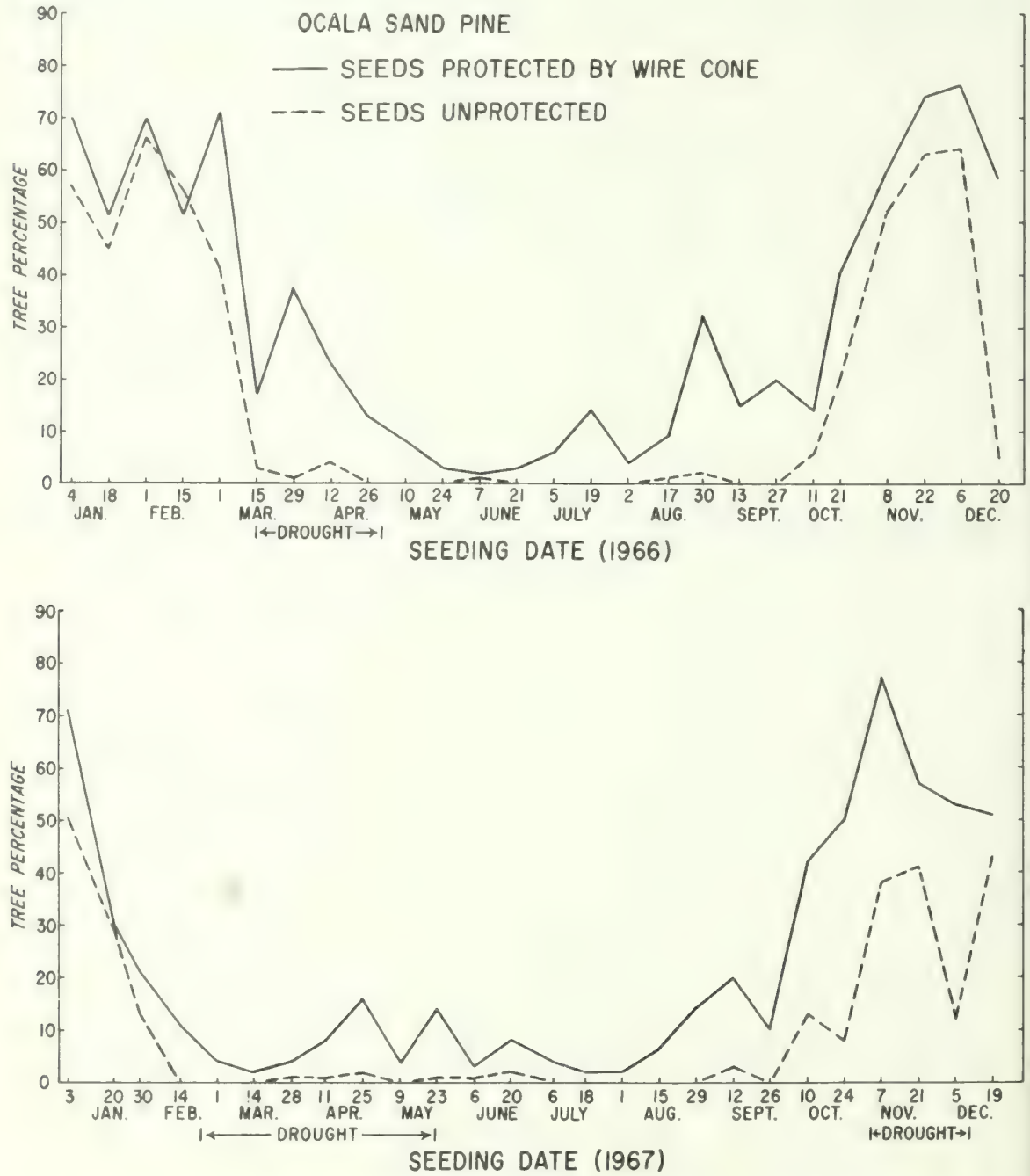
OCALA SAND PINE
SEEDS PROTECTED BY WIRE CONE
SEEDS UNPROTECTED
TREE PERCENTAGE
0 10 20 30 40 50 60 70 80 90
4 18 1 15 1 15 29 12 26 10 24 7 21 5 19 2 17 30 13 27 11 21 8 22 6 20
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
←DROUGHT→
SEEDING DATE (1966)
TREE PERCENTAGE
0 10 20 30 40 50 60 70 80 90
3 20 30 14 1 14 28 11 25 9 23 6 20 6 18 1 15 29 12 26 10 24 7 21 5 19
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
←DROUGHT→
←DROUGHT→
SEEDING DATE (1967)

Figure 4.--Tree percentages on protected and unprotected seed spots 52 weeks after the 1966 and 1967 plantings of Ocala sand pine.

Choctawhatchee Sand Pine

The smallest seeds planted were those of Choctawhatchee sand pine. They were either difficult to find or not a desirable source of food for predators during any but the latter portion of the year. Some seedlings were established from most of the plantings, but fall and winter plantings consistently produced the most seedlings (fig. 5). Adjusting these data for year-to-year variations in climate indicates that direct seeding of Choctawhatchee sand pine in northwest Florida has the highest probability of success if done no earlier than November 1 and no later than January 15.

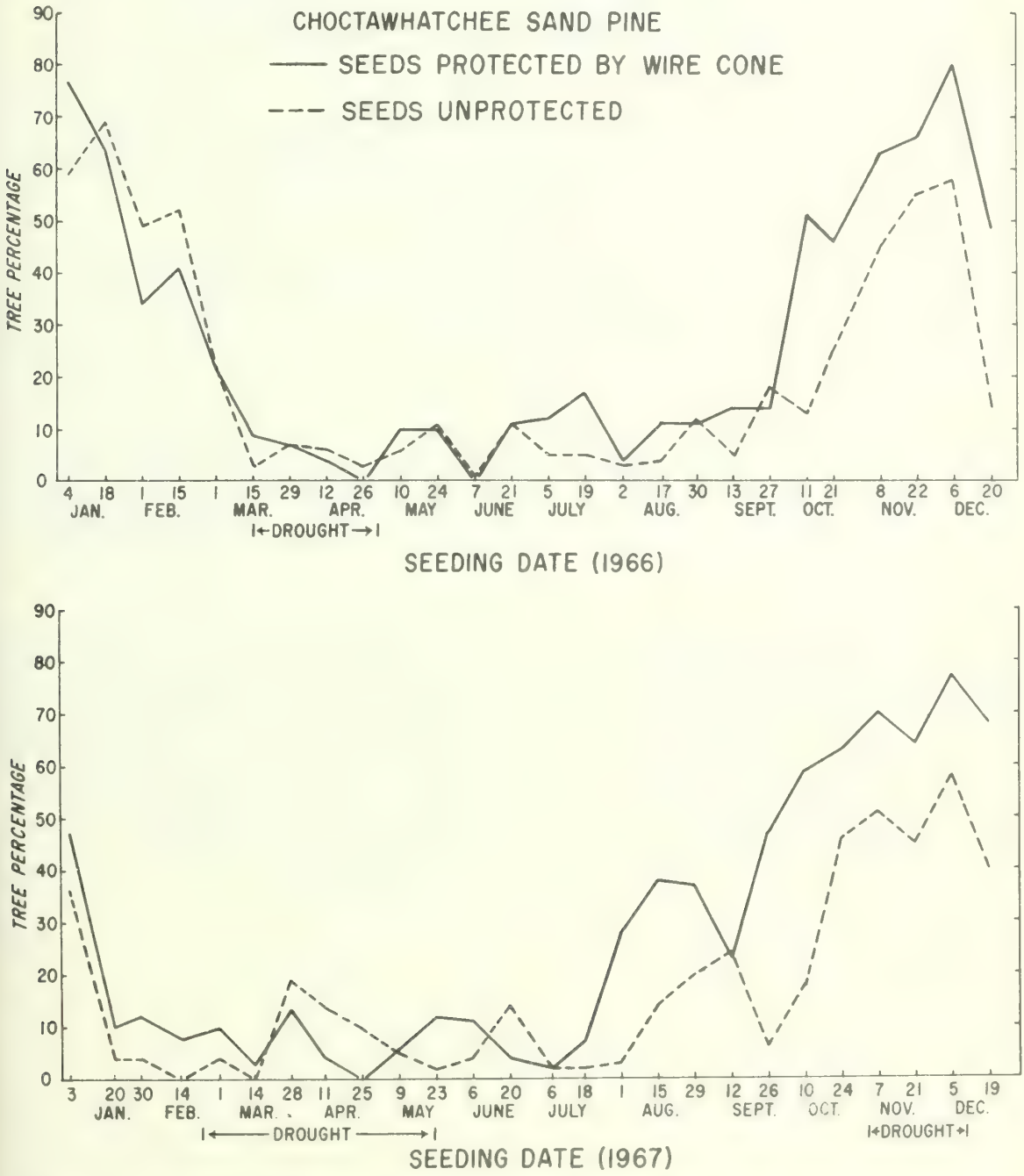
CHOCTAWHATCHEE SAND PINE
SEEDS PROTECTED BY WIRE CONE
SEEDS UNPROTECTED
TREE PERCENTAGE
0 10 20 30 40 50 60 70 80 90
4 18 1 15 1 15 29 12 26 10 24 7 21 5 19 2 17 30 13 27 11 21 8 22 6 20
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
I←DROUGHT→I
SEEDING DATE (1966)
TREE PERCENTAGE
0 10 20 30 40 50 60 70 80 90
3 20 30 14 1 14 28 11 25 9 23 6 20 6 18 1 15 29 12 26 10 24 7 21 5 19
JAN. FEB. MAR. APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
I←DROUGHT→I
I←DROUGHT→I
SEEDING DATE (1967)

Figure 5.--Tree percentages on protected and unprotected seed spots 52 weeks after the 1966 and 1967 plantings of Choctawhatchee sand pine.

Predators

Birds, mammals, and insects caused the loss of pine seeds and damaged newly germinated seedlings throughout the year. But as the seasons changed, so did the principal class of predators. Losses peaked during spring and fall, coincident with the influx of migratory birds, and declined during winter. Populations of insects and small mammals increased during spring and summer, and, even though seeds and browse of other plants were abundant in surrounding areas at that time, mammals and insects caused a considerable loss of pines. Insect activity waned during winter, but it did not entirely cease. Losses of pines to mammals increased as sources of other food diminished.

Small mammals appeared to be responsible for most of the seed losses. They also caused some loss of young seedlings. Three oldfield mice (Peromyscus polionotus) were seen on the study area, and evidence of eastern moles (Scalopus aquaticus) and southeastern pocket gophers (Geomys pinetis) was readily apparent. Gopher mounds covered some seed spots so deeply that neither germinating seeds nor small seedlings could survive. Moles burrowed under seed spots. Their burrows undoubtedly contributed to rapid drying of the droughty soil and to desiccation of pine radicles and roots. Both moles and pocket gophers are known to feed on roots of many plants (4), but no evidence was found here to indicate that pine roots form part of their diets.

Individual seed spots were located by predators with uncanny accuracy. Holes were made only where seeds had been planted. Two types of holes were found: one associated with a small pile of soil to one side (fig. 6), and the other a small conical hole with no pile of displaced soil. The former probably were made by small mammals digging for seeds and the latter by birds removing seedlings.

Ants were more numerous and destructive than all other insects (mole crickets, cutworms, and grasshoppers) and, with birds, probably were responsible for most of the seedling losses. Florida harvester ants (Pogonomyrmex badius (Latreille)) cut and carried cotyledons to their nests. Because neither primary nor secondary needles were cut, pine seedlings that survived the cotyledon stage usually escaped damage by ants. Ants also removed seeds. In one instance, a minute, unidentified ant moved a seed while other seeds were being planted. Insects other than ants were observed on seedlings as late as December. Neither the protective cone nor the repellent seed coating deterred them.

Figure 6.--Small mammals, presumably mice, located individual pine seeds with uncanny accuracy, even though the seeds were covered with soil. The keys point toward several of the excavations.

Protective cover from the young pine plantation and the stand of scrub hardwoods bordering the study area apparently provided small mammals ready access to the planted pine seeds. When protective ground cover is removed by intensive site preparation and the distance to a woods edge is thereby increased, losses of planted or even broadcast seeds may be drastically reduced (6).

Seed eaters showed a marked preference for the larger seeds. Losses were directly proportional to seed size, i.e., long leaf pine > slash pine > Ocala sand pine > Choctawhatchee sand pine.

Germination Tests

Cold storage did not adversely affect germinability of the pine seeds. As many or more seeds of all pines germinated at the end as at the beginning of the 2-year study, and, with the exception of slash pine, they germinated at least as fast (table 1).

Table 1.--Results of germination tests conducted at the beginning and end of the 2-year storage period

Test date	Longleaf pine	Slash pine	Ocala sand pine	Choctawhatchee sand pine
	Percent germination/Days for complete germination			
Feb. 1966	61/17	88/13	85/34	83/51
Jan. 1968	68/17	89/17	85/31	83/51

Rapid germination in the field shortens the time during which seeds are available to predators. However, results of the laboratory tests gave virtually no indication of how the seeds would perform in the field. Ocala sand pine seeds, for example, were among the last, and longleaf pine seeds were among the first, to complete germination in the laboratory, but both were quick to germinate in the field. Similarly, slash pine was first and Choctawhatchee sand pine was last to complete germination in the laboratory, but both were among the slowest to germinate in the field. Choctawhatchee sand pine seeds are mildly dormant. Both the speed and completeness of their germination can be increased by 2 weeks of cold, moist stratification (1). None of the pine seeds used here were stratified.

Rainfall and Air Temperature

Soil moisture one-fourth inch (6 mm) below the surface of the intensively prepared site was adequate for seedling establishment throughout most of the year. Only once during the 2-year test was tree percentage adversely affected by lack of moisture--during the latter part of a 13-week period (Feb. 22 to May 22, 1967) when 10 showers deposited less than 3 inches (7.6 cm) of rain. Low rainfall for periods as long as 6 weeks did not seriously hinder seedling establishment so long as soil moisture was at or close to field capacity at the start of the dry spell. The crust that forms at the soil surface shortly after a rain apparently inhibits evaporation, and the vegetation reinvading an intensively prepared sandhill site is too sparse to materially reduce the supply of moisture beneath the crust.

High temperatures limited seedling establishment. Increased exposure of the seeds and young seedlings to hot summer temperatures suppressed germination and caused tree percentages to decline. Correlations between tree percentage at 10 weeks and the average daily high in air temperature during the 10 weeks after planting were significant at the 1-percent level for longleaf and the sand pines. Few seedlings were established when air temperatures averaged 90° F (32° C) or more during this period (fig. 7). In 1966 and 1967, tree percentages were lowest for plots planted between March and September, when 10-week daily high temperatures averaged 85° F (29° C) and above. Comparable findings were obtained by Jones (3) with unstratified, repellent-treated seeds of slash pine in the Coastal Plains of Georgia; establishment was highest when field germination started after daily air temperatures were 70° F (21° C) or above and was completed before they reached 90° F (32° C).

Similar temperature means elicited differing tree percentages in the spring and fall. In the fall when the days were getting cooler, a given 10-week mean in temperature resulted in tree percentages as high as or higher than those for the same mean temperature in the spring. The photoperiod and solar spectrum also change with the seasons, and they may have had an effect on seed germination. However, their effects were not measured here.

Estimates of the optimum temperatures for seedling establishment were derived from the field data. Tree percentages at the end of 52 weeks were highest on both protected and unprotected spots when daily high temperatures during the 10 weeks after seeding averaged 71° F (22° C) or less and the corresponding lows averaged more than 38° F (3° C) (table 2). Furthermore, the highest tree percentages occurred over a range of high and low temperatures, and the range varied by species. Optimum high and low temperatures, for example, were generally lower for the sand pines than for longleaf and slash pines. They were highest for longleaf pine and lowest for Choctawhatchee sand pine.

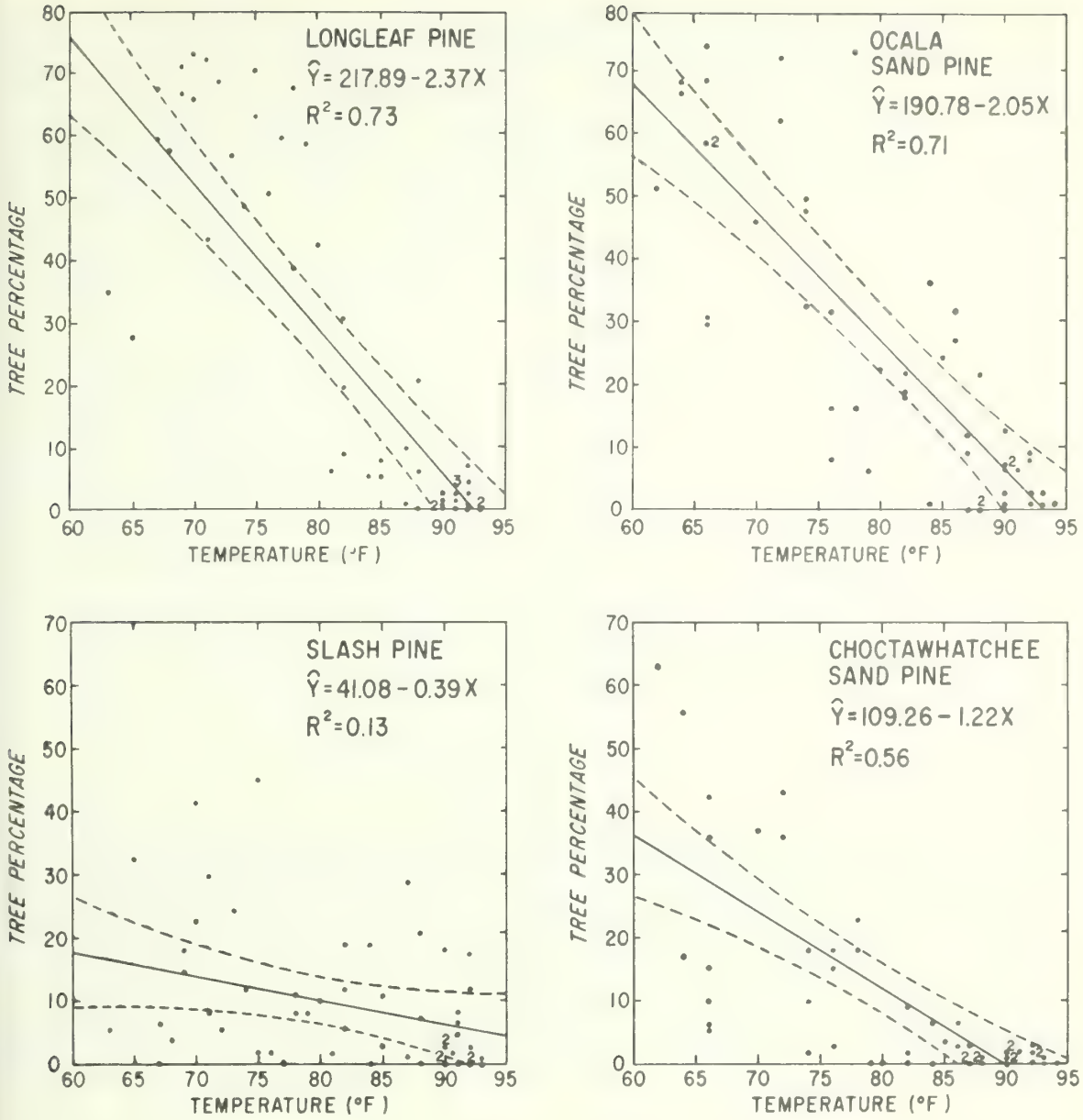

Figure 7.--The relationship between average air temperatures during the 10 weeks after seeding and tree percentages for longleaf, slash, and sand pines on protected spots as expressed by linear regression. The dashed lines represent the 99-percent confidence interval.

Table 2.--Ten-week means and ranges in high and low temperatures after those seedings that resulted in high tree percentages at the end of 52 weeks

Pine	Protection	52-week tree percent[1]	Air temperatures			
			High		Low	
			Mean	Range	Mean	Range
			°F (°C)			
Longleaf	With	60.2	70.9 (21.6)	64-79 (18-26)	41.0 (5.0)	32-51 (0-11)
	Without	34.0				
Slash	With	52.5	69.5 (20.8)	66-74 (19-23)	42.5 (5.8)	40-47 (4-8)
	Without	28.8				
Ocala sand	With	62.7	68.0 (20.0)	60-78 (16-26)	39.1 (3.9)	32-51 (0-11)
	Without	42.8				
Choctawhatchee sand	With	66.8	68.3 (20.2)	60-79 (16-24)	38.8 (3.8)	32-43 (0-6)
	Without	46.4				

[1]Averages for both protected and unprotected spots represent only those planting dates which resulted in tree percentages of 50 or more on protected spots.

Seeding Dates for Pines in the Sandhills

Climatic and edaphic factors unique to the sandhills preclude direct application of seeding data from areas differing physiographically. Because of the low productive potential of sandhill soils for most southern pines, not much work has been done with, and little is known about, seeding pines on droughty, infertile soil. Even a modicum of published data or experience is preferable to none, however. In sandhill areas where they are available, such data should be used either in preference to, or in conjunction with, the approximate planting dates to be presented here. But in sandhill areas where such guidelines are lacking, seeding dates for longleaf, slash, and the sand pines can be approximately determined from local climatological data in conjunction with the results of the seeding trials in northwest Florida.

The approximations to be presented are based primarily on the following observations from the present study: (1) Soil moisture beneath the surface of an intensively prepared sandhill site is adequate for seed germination and seedling establishment throughout most of the year. (2) When seeds are covered with one-fourth inch (6 mm) of sand, seedling establishment is best when daily highs in air temperature average no more than 68° to 71° F (20° to 22° C), depending on species, during the 10 weeks after seeding. Also involved is the relationship between temperature and soil depth.

The soil mitigates extremes in air temperature. Temperatures tend toward uniformity with increasing soil depth, i.e., highs tend to be lower and lows tend to be higher as depth increases. Therefore, temperatures most conducive to germination and establishment of pines adapted to the sandhills usually can be found at some depth during fall or winter. In sand, virtually the only limit to planting depth is the length of the hypocotyl that develops above the planted seed. If the cotyledons do not emerge from the soil, the seedling will die.

In the southernmost sandhills, average temperatures may exceed those listed here as optimum. In such locations, the insulating properties of the soil can be employed to advantage. Instead of planting seeds one-fourth inch deep, increase the depth to one-half inch (12 mm) or more. Depths of one-half to 1 inch (12 to 25 mm) have been recommended for longleaf and sand pines on the Astatula sands[1] of the Ocala National Forest in north central Florida (7). A similar solution may be employed at the northern extreme of the sandhills should low temperatures become limiting.

Approximate Seeding Dates in Various Sandhill Areas

As indicated, dates for seeding longleaf, slash, and sand pines in various sandhill areas can be approximated by using the results of this study in conjunction with published climatological data for the area involved. Table 2 lists the average 10-week highs and lows in air temperature which resulted in tree percentages of 50 or more on protected spots, as well as high percentages on those unprotected, when seeds were planted one-fourth inch deep. Climatological data published monthly by the Environmental Data Service of the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, can be used to determine when 10-week averages in daily highs will meet the optimum temperatures listed in table 2. (Because spring and summer seedings failed in the present study, land managers in other sandhill areas should consider only those periods during the dormant season when temperatures in their area parallel those in table 2.) The Environmental Data Service also publishes long-term averages for rainfall; land managers can use these to determine periods when rainfall will increase and to avoid recurrent periods when it will be extremely high or low.

Table 3 is provided for the convenience of land managers without ready access to a library of climatological data. Daily high temperatures are averaged for 10-week periods immediately following 15 dates at each of five widely separated locations representative of the sandhills. Long-term averages in monthly rainfall at these locations are also included. Records of temperature and rainfall from the fall and winter of 1971-72 were used. These data were adjusted to compensate for departures listed in the annual summary by the Environmental Data Service. Temperatures and dates may be interpolated at a given location. However, because of the proximity of some locations to the Gulf and the Atlantic Ocean and of the ameliorating effects of these large bodies of water on temperature, no interpolation of temperature should be made for points between any of the five listed locations.

How to Use the Seeding Guidelines

Use of the data in tables 2 and 3 to determine approximate dates for seeding pines in the five sandhill locations can be demonstrated by two examples. Approximate dates derived by this procedure are outlined in table 4 for each pine at the five locations.

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[1]Astatula sand is the hyperthermic counterpart of Kershaw sand. Both contain less than 5 percent fine-textured material and are droughty.

Table 3.--Average daily highs in air temperature during the 10 weeks after the indicated date and long-term averages in monthly rainfall at five sandhill locations

Date	North Central Florida (Lake County)				Northwest Florida (Okaloosa County)				Central Georgia (Bibb County)				Central South Carolina (Richland County)				Piedmont North Carolina (Moore County)			
	Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall		Temperature		Rainfall	
	°F	°C	In.	Cm	°F	°C	In.	Cm	°F	°C	In.	Cm	°F	°C	In.	Cm	°F	°C	In.	Cm
Sept. 3	86	30	7.2	18	83	28	6.2	16	82	28	3.4	9	80	27	4.2	11	78	26	4.0	10
17	82	28			80	27			77	25			75	24			74	23		
Oct. 1	80	27	4.3	11	75	24	2.6	7	71	22	2.4	6	70	21	2.4	6	68	20	3.0	8
15	77	25			72	22			68	20			67	19			65	18		
29	76	24			70	21			65	18			63	17			62	17		
Nov. 12	74	23	1.8	3	62	17	1.9	7	64	18	2.5	6	62	17	2.3	6	60	16	2.8	7
26	74	23			66	19			62	17			60	16			58	14		
Dec. 10	73	23	2.0	5	66	19	3.8	10	61	16	4.1	10	60	16	3.2	8	58	14	3.5	9
24	73	23			65	18			62	17			60	16			59	15		
Jan. 7	74	23	2.1	5	65	18	3.8	10	62	17	3.9	10	62	17	2.7	7	60	16	3.6	9
21	76	24			68	20			64	18			62	17			61	16		
Feb. 4	77	25	2.7	7	70	21	4.1	10	67	19	4.3	11	64	18	3.5	9	64	18	3.7	9
18	80	27			74	23			73	23			69	21			69	21		
Mar. 3	82	28	3.9	10	76	24	5.5	14	76	24	5.1	13	72	22	3.8	10	72	22	4.3	11
17	84	29			80	27			78	26			75	24			75	24		

Table 4.--Approximate seeding dates for longleaf, slash, and sand pines planted one-fourth inch (6mm) deep at five sandhill locations. (Approximations are based primarily on average daily highs in air temperature during the 10 weeks after planting and on average monthly rainfall. They may not agree with published data or local experience.)

Location and approximation	Longleaf pine	Slash pine[1]	Ocala sand pine	Choctawhatchee sand pine
North central Florida (Lake County[2])				
Range	Oct. 15 - Feb. 4	Oct. 29 - Jan. 21	Nov. 12 - Jan. 7	Nov. 12 - Jan. 7
Recommendation[3]	Nov. 12 - Feb. 4	Nov. 12 - Jan. 21	Nov. 12 - Jan. 7	Nov. 12 - Jan. 7
Northwest Florida (Okaloosa County[4])				
Range	Oct. 22 - Feb. 7	Oct. 29 - Feb. 4	Nov. 2 - Jan. 21	Nov. 2 - Jan. 21
Recommendation	Nov. 12 - Feb. 7	Nov. 12 - Feb. 4	Nov. 12 - Jan. 21	Nov. 12 - Jan. 21
Central Georgia (Bibb County)				
Range	Oct. 1 - Feb. 14	Oct. 6 - Feb. 11	Oct. 15 - Feb. 6	Oct. 15 - Feb. 6
Recommendation	Dec. 10 - Feb. 14	Dec. 10 - Feb. 11	Dec. 10 - Feb. 6	Dec. 10 - Feb. 6
Central South Carolina (Richland County)				
Range	Sept. 29 - Feb. 28	Oct. 1 - Feb. 23	Oct. 11 - Feb. 16	Oct. 11 - Feb. 16
Recommendation	Nov. 26 - Feb. 28	Nov. 26 - Feb. 23	Nov. 26 - Feb. 16	Nov. 26 - Feb. 16
Piedmont North Carolina (Moore County)				
Range	Sept. 24 - Feb. 28	Sept. 27 - Feb. 23	Oct. 1 - Feb. 16	Oct. 1 - Feb. 16
Recommendation	Nov. 26 - Feb. 28	Nov. 26 - Feb. 23	Nov. 26 - Feb. 16	Nov. 26 - Feb. 16

[1]Not recommended for droughty infertile sands that characterize most of the sandhills.
[2]Plant pine seeds one-half inch (12mm) deep.
[3]In this area, Thurmond (7) recommends planting longleaf and sand pine seeds one-half inch deep on prepared sandhill sites during October and November.
[4]Recommendations by Burns and Hebb (2) and McReynolds and Burns (5) differ slightly from those listed here because of temperature and rainfall differences between Calhoun and Okaloosa Counties.

Land managers selecting a favorable period for planting longleaf pine seeds in the vicinity of Moore County, N. C., would start with table 2, where it is shown that establishment of longleaf pine seedlings declines when 10-week averages in daily highs exceed 71° F (22° C). Interpolation of the data in table 3 shows that the average daily high in Moore County does not normally exceed 71° F from September 24 to February 28. However, table 3 also shows a decline in average monthly rainfall from September through November, followed by increasing rainfall and temperatures during the winter. Therefore, the best dates for planting longleaf pine seeds in this area would be from late November through February (table 4).

Land managers selecting planting dates for longleaf pine seeds in the vicinity of Lake County, Fla., would note from table 3 that the average daily highs in this area exceed 71° F throughout the year. However, the 71° F maximum was derived from data on longleaf pine seeds planted one-fourth inch deep. To compensate for excessively high temperatures in Lake County, therefore, land managers should plant longleaf pine seeds deeper than one-fourth inch. They should also time their plantings during the period of coolest weather and increasing rainfall-mid-November through early February (table 4). Thurmond (7) used machines to plant longleaf pine seeds on partially prepared sandhill land in this general area from September through December 1969. On the basis of this experience, he recommended planting pine seeds in this area at a depth of one-half to 1 inch (12 to 25 mm) during October and November. He attributed the comparatively low, but satisfactory, stocking obtained from the September planting to high temperatures and wet conditions that slowed germination and rotted the seed. He also attributed the exceptionally good stocking obtained from October, November, and December plantings to above-normal rainfall during December, January, and February. Therefore, when seeding pines in the vicinity of Lake County, Fla., the land manager is advised to follow Thurmond's recommendations and to depart from them only with caution. The seeding dates recommended for this area in table 4 on the basis of climatological data have not yet been field-tested and must await confirmation.

Similar reasoning was used to approximate all the planting dates listed in table 4. First, a range of planting dates was obtained from the data in tables 2 and 3; then, the recorded data on temperature and rainfall were used to select the recommended dates within that range.

RECOMMENDATION

Land managers interested in the direct seeding of pines in the southeastern sandhills are advised to follow published recommendations on planting dates in their locales. In areas where such information is lacking, the data presented here can be used as a starting point in developing a seeding schedule.

LITERATURE CITED

(1) Barnett, James P.
1973. Sand pine: Cone and seed traits, p. 55-66. In Sand pine symposium proceedings. USDA For. Serv. Gen. Tech. Rep. SE-2. Southeast. For. Exp. Stn., Asheville, N. C.

(2) Burns, Russell M., and Edwin A. Hebo
1972. Site preparation and reforestation of droughty, acid sands. USDA For. Serv. Agric. Handb. 426, 61 p.

(3) Jones, Earle P.
1971. Season for direct seeding slash pine in the middle and upper coastal plains of Georgia. USDA For. Serv. Res. Note SE-151, 7 p. Southeast. For. Exp. Stn., Asheville, N. C.

(4) Martin, A. D., H. S. Zini, and A. L. Nelson
1961. American wildlife and plants. 500 p. Dover Publications, Inc., New York.

(5) McReynolds, Robert D., and Russell M. Burns
1973. Direct seeding sand pines in the sandhills of northwest Florida, p. 107-115. In Sand pine symposium proceedings. USDA For. Serv. Gen. Tech. Rep. SE-2. Southeast. For. Exp. Stn., Asheville, N. C.

(6) McReynolds, Robert D., and Russell M. Burns
1975. Three machines for planting pine seeds in the sandhills. USDA For. Serv. Res. Note SE-218, 6 p. Southeast. For. Exp. Stn., Asheville, N. C.

(7) Thurmond, G.
1971. Direct seeding longleaf and sand pine on the Seminole Ranger District of the Ocala National Forest. USDA For. Serv., South. Reg., 15 p. [Unnumbered publ.]

Burns, Russell M., and Robert D. McReynolds
1975. Planting dates for longleaf, slash, and sand pine seeds in the southeastern sandhills: Effect of temperature and rainfall. USDA For. Serv. Res. Pap. SE-143, 17 p. Southeast. For. Exp. Stn., Asheville, N. C.

On a prepared sandhill site in northwest Florida, repellent-treated seeds of longleaf, slash, and Ocala and Choctawhatchee sand pines were planted on exposed and protected seed spots at biweekly intervals for two consecutive years. Spring and summer seedings failed. Many of the seeds and seedlings were lost to small mammals, birds, and insects. Seedling establishment was depressed by high temperatures, but it was not limited by available soil moisture except during prolonged droughts. For the four pines, seedling establishment was best when daily high temperatures averaged no more than 71° F (22° C) and daily lows no less than 38° F (3° C) during the 10 weeks after seeding. In sandhill areas where local guidelines are lacking, these findings can be used with published climatological data to determine the best time to seed the four pines.

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SDA Forest Service Research Paper SE-144 November 1975

How to Keep One-Third of Georgia in Pine

by

Stephen G. Boyce

and

Joe P. McClure

MAY 4 1977

U.S. Department of Agriculture - Forest Service

Southeastern Forest Experiment Station

Asheville, North Carolina

How to Keep One-Third of Georgia in Pine

by

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Asheville, North Carolina

Pine timber production in Georgia has been maintained primarily by the rotation of retired cropland to pine forests. However, cropland retirement can no longer be relied upon as a major source of new pineland. This report describes some actions that would keep about one-third of Georgia in pine forests. We identified these actions by examining the previous use of lands generated to pine, determining the uses of lands after the harvest of pine, and identifying activities that initiate and stimulate shifts of lands to and from pines.

The actions we recommend are:

1. Reforest every harvested pine stand to full stocking.

2. Delay the harvest of loblolly (Pinus taeda L.) and slash (P. elliottii Engelm.) pine stands until age 30 or later.

3. Reduce thinnings and related timber stand improvements in pine stands.

4. Use timber stand improvement primarily to convert oak-pine stands to pine.

5. Stop converting natural stands of longleaf (P. palustris Mill.), shortleaf (P. echinata Mill.), pond (P. serotina Michx.), and Virginia (P. virginiana Mill.) pine to loblolly and slash pine.

SOURCE OF DATA AND METHODS

Permanent Forest Survey plots were established throughout Georgia in 1961 (Larson and Spada 1963) and remeasured in 1972 (Knight and McClure 1974). The net changes between surveys in area devoted to seven types of land use were examined. Changes in land use on individual plots were also noted.

The types of land use recognized were:

Loblolly pine ecosystem.--All stands containing 50 percent or more pine and with most of the pine being loblolly.

Slash pine ecosystem.--All stands containing 50 percent or more pine and with most of the pine being slash.

Minor pines.--All stands containing 50 percent or more pine and with most of the pine being shortleaf, longleaf, Virginia, white, pond, spruce, pitch, or sand pine. Small amounts of hemlock and redcedar were included.

Oak-pine.--All stands containing 25 to 49 percent pine and the remainder hardwoods, usually upland oaks.

Hardwoods.--All stands containing 75 percent or more hardwoods. Some southern cypress was included as "hardwoods."

Agriculture.--All idle farmland, improved pasture, and cropland.

Urban.--Areas within the legal boundaries of cities and towns; suburban areas developed for residential, industrial, or recreational purposes; schoolyards; cemeteries; roads; railroads; airports; beaches; water impoundments; powerlines and rights-of-way; and other nonforest and forest land reserved for urban uses such as hunting, fishing, and hiking.

Six actions initiated or stimulated changes in land use.

Natural succession.--A change in forest type when there was no evidence of human disturbance since 1961. However, thinnings and other forms of timber stand improvement prior to 1961 may have speeded natural succession between 1961 and 1972.

Disturbance.--Any action causing change and leaving evidence. Causes of disturbance include but are not limited to wildlife, prescribed burning, drainage, diseases, insects, ice, severe storms, flooding, grazing, turpentining, and construction of fences, woods roads, and fire breaks.

Harvest.--The removal of dominant trees for products, except for timber stand improvement.

Timber stand improvement.--All preharvest cuttings such as thinning, cleaning, release, girdling or poisoning undesirable trees, and intermediate cuttings. Also included were clearings and conversions of species, site preparations, and artificial regenerations.

Timber stand improvement in pine stands consisted almost entirely of actions to reduce stand density. In the oak-pine stands and in some of the hardwood stands, timber stand improvement consisted of those actions to favor pine and to improve the quality of the residual hardwood stands.

Urbanization.--The conversion or the reservation of forests for urban use.

Agricultural clearing.--The removal of forests for pasture or cropland.

CROPLAND ⟶ PINE ⟶ HARDWOOD

Shifting agriculture has been an important, although passive, way to generate southern pine forests since early settlement (Ashe 1915; Nelson 1957; Plummer [n.d.]). The clearing of "new land" and the retirement of cropland were until about 1965 the most important actions driving the rotation of forests to cropland and back to forests (Brender 1974; Boyce 1974). Most retired cropland naturally seeded to loblolly and slash pine if the environment was appropriate. However, in recent years most clearings of land for agriculture have shifted from the areas suitable for pine to the alluvial and flat areas of the Mississippi Delta (Frey and Dill 1971), southern Florida, and the wetland hardwood forests near the coasts (Whisler 1974) (fig. 1).

Planting and other forms of artificial regeneration are not compensating for the reduced rate of cropland retirement. The planting of pines, mostly on retired cropland, increased after 1950 (Larson 1957). Yet today 76 percent of the loblolly and slash pine area east of the Mississippi River is in natural stands, and most of these stands seeded on cropland retired since 1944 (Boyce and others 1975a, 1975b).

In Georgia between 1961 and 1972 there was a net loss of acres in loblolly pine, a gain in slash pine acreage, and a decline of acres in the minor pines (table 1). There was an increase in the acreage of oak-pine types. Net acreage of hardwood forests and agricultural land declined. And urbanization permanently removed some forest land from timber production. Net loss of forests was 949,100 acres.

These relatively small net changes, however, mask much larger rotational changes on lands suitable for growing pine timber. Almost 31 percent of the land occupied by loblolly pine in 1961 rotated to some other use by 1972 (table 1). Some 30 percent of the 1972 loblolly area was rotated from some other use to loblolly pine. The rotation rates out of and into oak-pines were 61.6 and 75.4 percent. All of the seven types of land use had relatively high rates of change during this period. The smallest rotation rate was agriculture with 13.9 percent added and 10.1 percent removed.

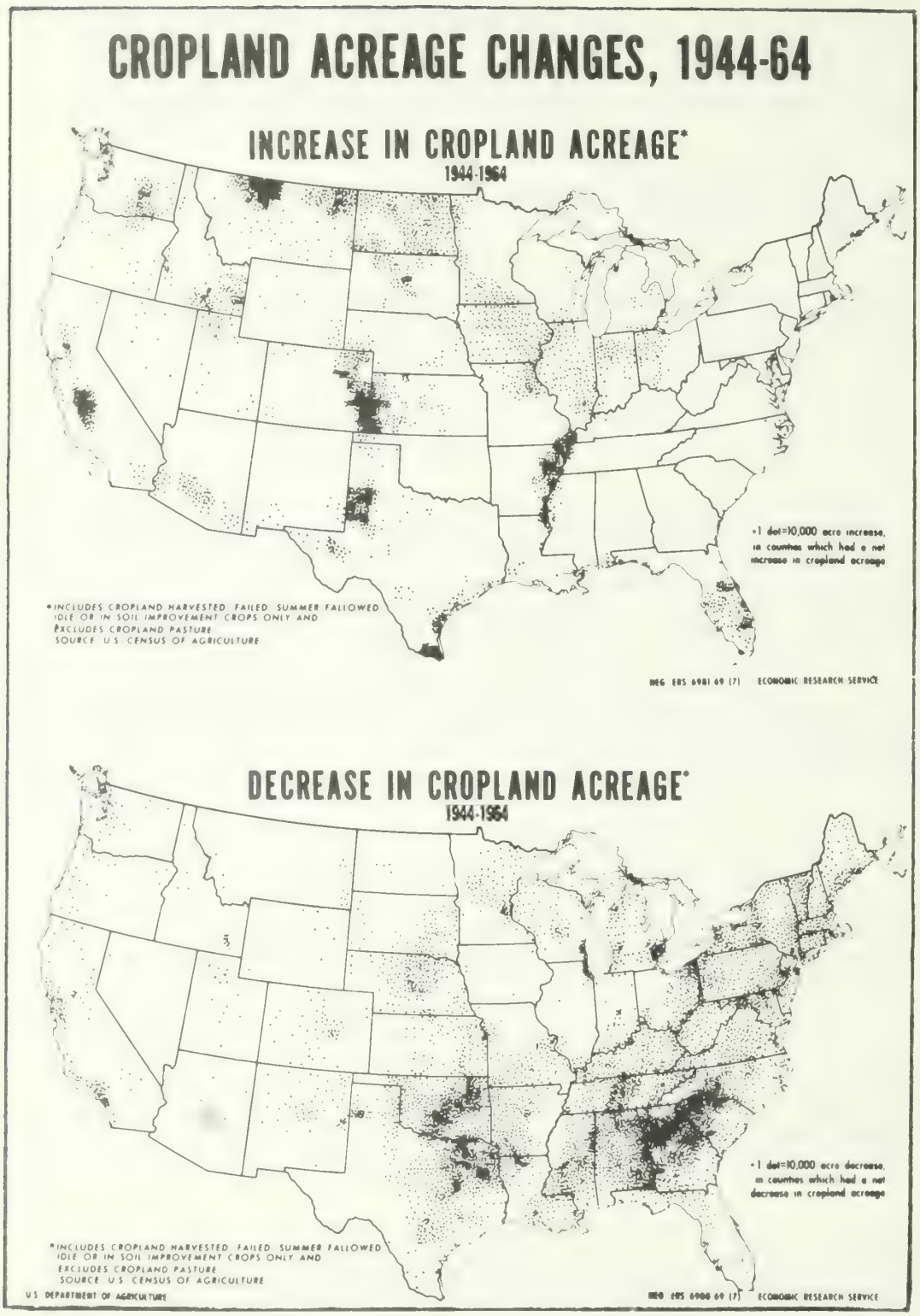
CROPLAND ACREAGE CHANGES, 1944-64
INCREASE IN CROPLAND ACREAGE*
1944-1964
•1 dot=10,000 acre increase, in counties which had a net increase in cropland acreage
•INCLUDES CROPLAND HARVESTED FAILED SUMMER FALLOWED IDLE OR IN SOIL IMPROVEMENT CROPS ONLY AND EXCLUDES CROPLAND PASTURE
SOURCE U.S. CENSUS OF AGRICULTURE
ECONOMIC RESEARCH SERVICE
DECREASE IN CROPLAND ACREAGE*
1944-1964
•1 dot=10,000 acre decrease, in counties which had a net decrease in cropland acreage
•INCLUDES CROPLAND HARVESTED FAILED SUMMER FALLOWED IDLE OR IN SOIL IMPROVEMENT CROPS ONLY AND EXCLUDES CROPLAND PASTURE
SOURCE U.S. CENSUS OF AGRICULTURE
U.S. DEPARTMENT OF AGRICULTURE
ECONOMIC RESEARCH SERVICE

Figure 1.--Increases and decreases in cropland acreage in the United States between 1944 and 1964.

Table 1.--Land areas, net changes, and rotations for seven types of land use in Georgia from 1961 to 1972

Type of land use	1961 area	1972 area	Net change	Rotation	
				Removed	Added
	- - - - - - - - - - - Thousand acres - - - - - - - - - - -				
Loblolly pine	5,077.8	5,014.9	-62.9	1,556.1	1,493.2
Slash pine	4,102.4	4,527.6	+425.2	1,101.1	1,526.3
Minor pines	3,970.8	2,782.6	-1,188.2	2,036.4	848.2
Oak-pines	3,642.2	4,142.9	+500.7	2,244.7	2,745.4
Hardwoods	8,994.9	8,371.0	-623.9	2,592.6	1,968.7
Agriculture	9,466.0	9,105.4	-360.6	1,317.2	956.6
Urban	1,872.7	3,084.8	+1,212.1	0	1,212.1
Total[1]	37,126.8	37,029.2	[2]-97.6	10,848.1	10,750.5

[1]Excludes all water areas.

[2]Reduction due to exclusion of net water areas.

The sections that follow describe rotations for each of the land uses in relation to every other land use and in relation to the actions that bring about land rotations.

LOBLOLLY PINE

Boyce and others (1975a) divided the loblolly pine ecosystem east of the Mississippi River into Timber Production Provinces. In Georgia the ecosystem occurs in five Timber Production Provinces (fig. 2). These Timber Production Provinces identify areas of demonstrated biological potential for timber production for loblolly pine (table 2). These areas have changed very little in 100 years (Nelson 1957; Wahlenberg 1960; Plummer [n.d.]). However, the proportion of land in loblolly pine does change.

The 11-year additions to loblolly pine came primarily from agricultural land retirement, from the minor pines, and from the oak-pine type (table 3). Most of the acres added to loblolly pine from the minor pines and the oak-pines were by site preparation and planting.

Of the 447,600 acres that rotated from agriculture to loblolly pine, 178,100 acres were artificially reforested, and 269,500 acres seeded naturally. These data emphasize again the importance of large areas of seedbeds suitable for natural regeneration for maintaining the ecosystem.

Most of the cropland that was occupied by loblolly pine was in the Piedmont Timber Production Province, where two-thirds of the loblolly pine area is located and where large areas of cropland were retired. This is also the Province with the largest area of loblolly pine plantations (table 2). Most of these plantings are on retired cropland.

Figure 2.--Timber Production Provinces for loblolly pine east of the Mississippi River.

The rotations between loblolly and slash pine of 110,000 and 139,200 acres suggest considerable uncertainty about which pine to encourage on certain areas (table 3). This uncertainty is most prevalent in the Gulf Coast Timber Production Province.

Table 2.--Area of the loblolly pine ecosystem in Georgia, by Timber Production Province and origin of the stands, 1972

Timber Production Province	Total	Origin of stand	
		Natural	Planted
	- - Thousand acres - -		
Piedmont	3,280	2,857	423
Fall Line	674	572	102
Gulf Coast	616	518	98
Foothills	394	348	46
Blue Ridge	45	30	15
Total[1]	5,009	4,325	684

[1]About 5,900 acres of loblolly pine are outside the Timber Production Provinces.

Table 3.--Rotations in land area for loblolly pine in Georgia from 1961 to 1972

Type of land being rotated	Removed from loblolly	Added to loblolly	Net change
	- - - Thousand acres - - -		
Oak-pine	678.8	374.3	-304.5
Hardwoods	325.7	162.0	-163.7
Minor pines	176.7	370.1	+193.4
Urban	138.6	0	-138.6
Agriculture	126.3	447.6	+321.3
Slash pine	110.0	139.2	+29.2
Total change	1,556.1	1,493.2	-62.9

More than 1 million acres of land rotated from loblolly pine to oak-pine and hardwoods (table 3). This rotation was speeded by harvesting (table 4). Of the harvested acres, 54 percent were not reforested to loblolly pine. It is apparent that reforestation often is not an integral part of the harvesting process and that harvesting is the most important action initiating the rotation of acreage from loblolly pine.

Table 4.--Rotation of land from loblolly pine in Georgia, by type of action, 1961 to 1972

Type of action	Area affected	Proportion of area rotated to another use	
	Thousand acres		Percent
Harvest	947.8	513.0	54
Timber stand improvement	1,395.6	356.5	26
Natural succession	2,008.6	352.2	18
Urbanization	138.6	138.6	100
Agriculture	126.3	126.3	100
Disturbance	460.9	69.5	15
Total	5,077.8	1,556.1	31

Timber stand improvement is the second most important action reducing loblolly pine acreage. Of the 1,395,600 acres treated, 26 percent rotated to another forest type during the 11-year period (table 4). Timber stand improvement in pine stands consisted of thinnings, cleanings, and intermediate cuttings. Commercial thinning was the most frequent kind of timber stand improvement. Intermediate cuttings speed the rate of natural succession to oak-pine and hardwood types (Boyce 1951). These kinds of timber stand improvements reduce the accumulation of cubic volume at culmination of mean annual increment (Schultz 1975), but they increase average diameter of the residual trees.

Natural succession in undisturbed stands also converts loblolly pine to oak-pine and hardwoods. The 352,200 acres naturally rotated from loblolly pine represent 18 percent of the undisturbed area. Some of these stands may have received timber stand improvement or disturbance before 1961. Harvesting, timber stand improvement, and natural succession accounted for 79 percent of the rotation of land from loblolly pine. These losses were not compensated for by converting oak-pine and hardwoods to loblolly pine (table 3).

Rotation from disturbances, urbanization, and agriculture represents 21 percent of the losses. Land cleared for agriculture may eventually be returned to forest, but losses to urbanization are probably permanent.

SLASH PINE

The slash pine ecosystem is concentrated in Georgia, Florida, and South Carolina (fig. 3). The range of the ecosystem in Georgia has been extended to the northwest by extensive plannings in the Tifton and Plantation Timber Production Provinces. Plantations account for about 40 percent of the total ecosystem (Boyce and others 1975b). In Georgia the proportion of plantations is about 44 percent (table 5).

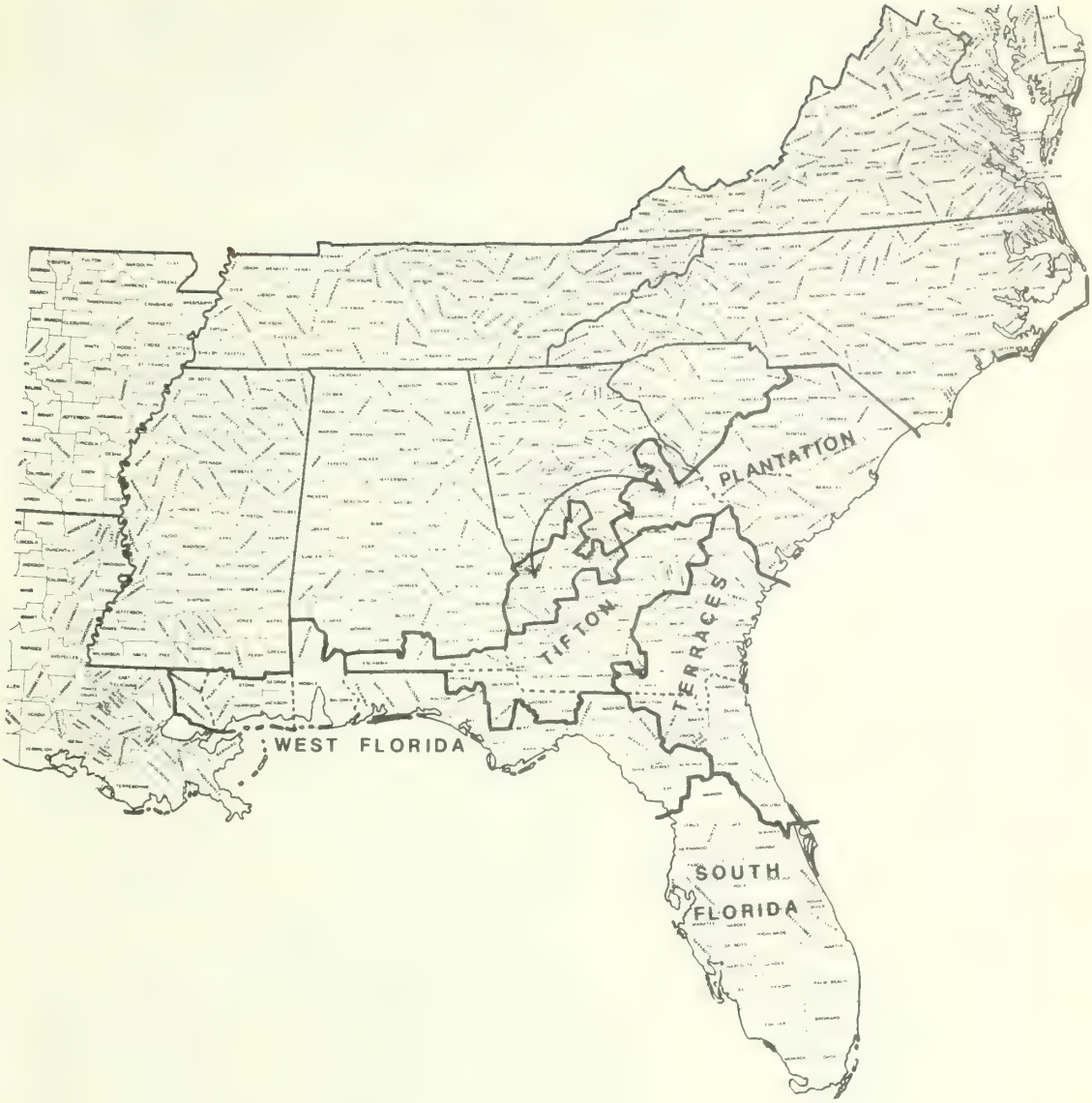

Figure 3.--Timber Production Provinces for slash pine.

Most of the land rotations with slash pine were in the Tifton and Terraces Timber Production Provinces. These Provinces have the highest biological potential for slash pine timber production. The Plantation Timber Production Province is where the minor pine species, mostly longleaf, were converted to slash pine.

Slash pine had a net rotation gain of about 425,200 acres (table 6). This gain came from the conversion of minor pines to slash pine and the reforestation of retired croplands to slash pine. About 101,000 acres of these retired croplands seeded naturally to slash pine and 261,700 acres were planted. About 597,400 acres of the conversions to slash pine came from oak-pine, hardwoods, and loblolly pine.

Table 5.--Area of the slash pine ecosystem in Georgia, by Timber Production Province and stand origin, 1972

Timber Production Province	Total	Origin of stand	
		Natural	Planted
	- - - Thousand acres - - -		
Terraces	2,518	1,543	975
Tifton	1,582	983	599
Plantation	423	26	397
Total[1]	4,523	2,552	1,971

[1]About 4,600 acres of slash pine plantations are outside the Timber Production Provinces.

Table 6.--Rotations in land area for slash pine in Georgia from 1961 to 1972

Type of land being rotated	Removed from slash	Added to slash	Net change
	- - - Thousand acres - - -		
Oak-pine	359.7	282.9	-76.8
Hardwoods	239.2	204.5	-34.7
Loblolly	139.2	110.0	-29.2
Minor pines	126.2	566.2	+440.0
Urban	123.9	0	-123.9
Agriculture	112.9	362.7	+249.8
Total change	1,101.1	1,526.3	+425.2

About 27 percent of the 1961 slash pine area was lost to some other use (table 7). The most important actions stimulating these losses were harvesting, natural succession, and timber stand improvement. Of the area harvested, 39 percent was not reforested to slash pine. About 22 percent of the undisturbed areas naturally changed to some other forest type and about 15 percent of the stands receiving some form of timber stand improvement were converted to other forest types. Disturbance was of minimum significance. However, about 123,900 acres rotated to urban use and 112,900 acres went to agriculture.

Slash pine is a favored species. Considerable investments are made to convert stands of the minor pines, oak-pines, and hardwoods to slash pine. These conversions plus cropland retirement added 1,416,300 acres of land to the slash pine ecosystem (table 6). Yet, harvesting, natural succession, and timber stand improvement removed 773,100 acres (table 7). Had every harvested stand been reforested, the net gain to slash pine could have been 797,900 acres rather than 425,200 acres.

Table 7.--Rotation of land from slash pine in Georgia, by type of action, 1961 to 1972

Type of action	Area affected	Proportion of area rotated to another use	
	Thousand acres		Percent
Harvest	943.6	372.7	39
Natural succession	1,157.7	253.8	22
Timber stand improvement	995.1	146.6	15
Urbanization	123.9	123.9	100
Agriculture	112.9	112.9	100
Disturbance	769.2	91.2	12
Total	4,102.4	1,101.1	27

MINOR PINES

Loblolly and slash pine are the most important species for reforestation and intensive culture in Georgia. A number of less favored pines contribute to timber production. Most stands of these species--shortleaf, longleaf, pond, and Virginia pine--are of natural origin. Relatively small areas of these species are being planted. The distribution of minor pines is shortleaf pine, 46 percent; longleaf pine, 30 percent; pond pine, 8 percent; Virginia pine, 14 percent; and other species, 2 percent.

More than 2 million acres (table 8) of land rotated from the minor pines. Most of these lands changed to slash pine, oak-pine, and loblolly pine. Between 1961 and 1972, 780,400 acres of longleaf pine, more than half of all this pine's area in Georgia, was converted to some other use. The remaining conversions came primarily from shortleaf pine (405,800 acres) and pond pine (82,400 acres). The net loss from these minor pine species was nearly 1.2 million acres.

Harvesting, timber stand improvement, and natural succession rotated much of the longleaf, shortleaf, and pond pine to other uses (table 9). During the 11-year period half of the land in these minor pines changed to another use.

Table 8.--Rotations in land area for the minor pines in Georgia from 1961 to 1972

Type of land being rotated	Removed from minor pines	Added to minor pines	Net change
	- - - - Thousand acres - - - -		
Slash pine	566.2	126.2	-440.0
Oak-pine	525.1	313.4	-211.7
Loblolly pine	370.1	176.7	-193.4
Hardwoods	249.9	103.5	-146.4
Urban	170.0	0	-170.0
Agriculture	155.1	128.4	-26.7
Total change	2,036.4	848.2	-1,188.2

Table 9.--Rotation of land from the minor pines in Georgia, by type of action, 1961 to 1972

Type of action	Area affected	Proportion of area rotated to another use	
	Thousand acres		Percent
Harvest	965.1	731.4	76
Natural succession	1,250.3	457.2	37
Timber stand improvement	1,007.9	416.1	41
Urbanization	170.0	170.0	100
Agriculture	155.1	155.1	100
Disturbance	422.4	106.6	25
Total	3,970.8	2,036.4	51

The rotation of more than 457,200 acres with no disturbance (table 9) suggests a rapid rate of natural succession to oak-pine and hardwoods. This rate of natural succession, 37 percent in 11 years, is much faster than for loblolly and slash pine. The reasons for this rapid change are not readily apparent from the data, but discrimination against these pines in the application of timber stand improvement practices may be a cause.

The very large rate of land rotation from the minor pines to slash pine and loblolly pine and the net loss of more than 1.1 million acres suggest a greatly reduced production of pine timber from shortleaf, longleaf, pond, and Virginia pine. These minor pines are inherently better

adapted to natural regeneration and survival on the lands where they naturally occur than loblolly and slash pine. When areas are converted from minor pines to loblolly or slash pine, much of the natural biological potential for timber production from these minor pines is lost.

OAK-PINE

Oak-pine is an unstable and transitory forest type. In 11 years, 62 percent of all the oak-pine land was rotated to other uses. Most of these lands went to hardwood forest and to the pines (table 10). Relatively small amounts went to agriculture and urbanization. The relatively large rotation to hardwoods is caused partly by the narrow range of hardwoods admitted in the oak-pine type. An area is classed as oak-pine only when there are 51 to 74 percent hardwoods in the stand. Thus, relatively small changes in the proportion of pine or hardwoods can change the classification to hardwood or pine. Also, some of the 1 million acres rotated from hardwoods to oak-pine may represent failures of timber stand improvement to completely change a hardwood stand to pine.

The largest source of oak-pine land is the pine stands (table 10), and the oak-pine type is a primary source of land for conversion to pine. Disturbances of pine stands increase the amount of hardwoods and speed succession to oak-pine. These oak-pine stands often rotate to hardwood stands that are referred to as "low-quality hardwoods" and "hardwoods growing on pine sites" (Anderson 1974; Murphy and Knight 1974). The large area rotated from pine to oak-pine suggests the need for some changes in timber stand improvement and harvesting practices.

Table 10.--Rotations in land area for oak-pine in Georgia from 1961 to 1972

Type of land being rotated	Removed from oak-pine	Added to oak-pine	Net change
	- - - - Thousand acres - - - -		
Hardwoods	1,077.4	1,140.5	+63.1
Loblolly pine	374.3	678.8	+304.5
Minor pines	313.4	525.1	+211.7
Slash pine	282.9	359.7	+76.8
Urban	102.9	0	-102.9
Agriculture	93.8	41.3	-52.5
Total change	2,244.7	2,745.4	+500.7

The total acreage of oak-pine could be greatly reduced by diverting efforts from the conversion of hardwoods to the reforestation of every harvested stand of pine. Between 1961 and 1972, a large effort was made to convert oak-pine to pine (table 11). At the same time inadequate effort was devoted to reforesting every harvested pine stand. These latter stands naturally succeed to oak-pine or hardwoods, which are more costly to convert than to reforest at the time of harvest. It would appear to be more efficient to invest first in the reforestation of every harvested pine stand and second in converting oak-pine to pine. Had every harvested loblolly and slash pine stand been reforested, 1,038,500 acres would not have rotated to oak-pine (678,800 + 359,700, table 10).

HARDWOODS

More than 2 million acres of land rotated between hardwoods and oak-pine (table 12). Years ago, these lands rotated through agriculture. After retirement from agriculture these lands rotated to pine, oak-pine, and hardwoods. These rotated hardwood stands represent most of the "low-quality hardwoods" and "hardwoods on pine sites" (Anderson 1974; Murphy and Knight 1974). Between 2 and 3 million acres of such land seem to be rotating among the hardwood and pine classifications (table 12).

The lands that have rotated through agriculture to hardwoods often have some pines. Whenever the volume of pines exceeds 25 percent, the stands are classified as oak-pine. This classification changes as the proportion of pine changes from below to above 25 percent. Some of this change represents a flow of land from hardwoods through slash, loblolly, and minor pines and back to oak-pine and hardwoods. Some change is an oscillation between oak-pine and hardwoods.

Some of the oscillation to above and below the 25 percent proportion of pine is initiated by timber stand improvement (table 13). About 32 percent of the hardwood stands receiving timber stand improvement rotated

Table 11.--Rotation of land from oak-pine in Georgia, by type of action, 1961 to 1972

Type of action	Area affected	Proportion of area rotated to another use	
	Thousand acres		Percent
Natural succession	1,854.6	953.6	51
Harvest	646.0	474.6	73
Timber stand improvement	619.7	391.2	63
Disturbance	325.2	228.6	70
Urbanization	102.9	102.9	100
Agriculture	93.8	93.8	100
Total	3,642.2	2,244.7	62

Table 12.--Rotations in land area for hardwoods in Georgia from 1961 to 1972

Type of land being rotated	Removed from hardwoods	Added to hardwoods	Net change
	- - - - Thousand acres - - - -		
Oak-pine	1,140.5	1,077.4	-63.1
Urban	513.7	0	513.7
Agriculture	468.4	76.5	-391.9
Slash	204.5	239.2	+34.7
Loblolly	162.0	325.7	+163.7
Minor pines	103.5	249.9	+146.4
Total change	2,592.6	1,968.7	-623.9

Table 13.--Rotation of land from hardwoods in Georgia, by type of action, 1961 to 1972

Type of action	Area affected	Proportion of area rotated to another use	
	Thousand acres		Percent
Natural succession	5,048.3	934.2	19
Urbanization	513.7	513.7	100
Agriculture	468.4	468.4	100
Timber stand improvement	1,245.8	401.9	32
Harvest	1,056.9	169.8	16
Disturbance	661.8	104.6	16
Total	8,994.9	2,592.6	29

to some other forest type. A large amount of hardwood went to oak-pine (table 10). Natural succession rotated about 934,200 acres from hardwoods to another kind of forest. Much of this natural succession may have been initiated by timber stand improvements that were not apparent on the re-measured plots in 1972.

Several kinds of forests are classified as hardwoods. About 3,154,000 acres of hardwoods in Georgia are on wetlands (Boyce and Cost 1974). Most of these lands are unsuitable for pine, except after drainage. Drainage and clearing for agriculture are now occurring primarily in these wetlands (Whisler 1974) (fig. 1). About 468,400 acres of hardwoods, mostly in the wetlands, were cleared for agriculture since 1961 (table 12).

Natural succession, urbanization, agriculture, and timber stand improvement are the most important actions for removing land from the hardwood types (table 13). Only 16 percent of the harvested hardwood stands went to another use. Urbanization removed 513,700 acres of the hardwood forest. These removals included about 325,000 acres for a wildlife refuge, and other lands for highways, urban communities, water impoundments, and other uses (Knight 1973).

The conversion of hardwood stands to pine is apparently more costly than the reforestation of pine stands immediately after harvest (Yoho and others 1969). It would appear to be most efficient to invest first in reforestation of every harvested pine stand, second in converting oak-pine to pine, and third in the conversion of hardwoods to pine.

AGRICULTURE

Recent data suggest an increased stability of agricultural land in the South (table 14). The stabilization of agricultural land, with little or no rotation, could greatly reduce the production of southern pine timber (Boyce 1974). Agriculture has the smallest rate of rotation of any of the seven uses examined for the 11-year period.

From early settlement there has been a rotation of harvested forest lands to croplands and of retired croplands to pine. The rate of rotation was apparently fast enough to maintain some unknown but relatively large area in pine at least until about 1900 (Ashe 1915; Plummer [n.d.]). The net amount of forest cleared for agriculture was greater than the net amount of cropland retired to forest until about 1930 (Wooten and Anderson 1957).

Table 14.--Rotations in land area for agriculture in Georgia from 1961 to 1972

Type of land being rotated	Removed from agriculture	Added to agriculture	Net change
	- - - - Thousand acres - - - -		
Loblolly pine	447.6	126.3	-321.3
Slash pine	362.7	112.9	-249.8
Urban	250.0	0	-250.0
Minor pines	128.4	155.1	+26.7
Hardwoods	76.5	468.4	+391.9
Oak-pine	41.3	93.8	+52.5
Total change	1,306.5	956.5	-350.0

In Georgia total cropland increased until 1940, then rapidly declined until 1965 (fig. 4). From 1940 to 1970 the acres of cropland harvested for crops declined from 8,802,000 acres to 3,411,000 acres. Most of this land naturally seeded to pine and some was planted to pine (Spillars and Eldredge 1943; Larson 1957; Larson and Spada 1963; Knight and McClure 1974). Some retired cropland was changed to pasture and other uses. Now, there is not enough cropland to replace the natural pine forests. In 1972, about 3.5 million acres of cropland were harvested but there were more than 9.3 million acres of natural pine forests (Knight and McClure 1974). It is unlikely that rotations of land from a relatively stable 3.5 million acres of cropland can maintain the current area of natural pine forest.

Between 1961 and 1972 retired cropland provided 27 percent of the land added to the loblolly and slash pine ecosystems. The minor pines, mostly longleaf pine, provided 31 percent of the land; oak-pine, 22 percent; and the hardwoods, 12 percent (computed from tables 3 and 6). With a reduction in the amount of land available from agriculture and the minor pines, more efficient use must be made of land now in pines.

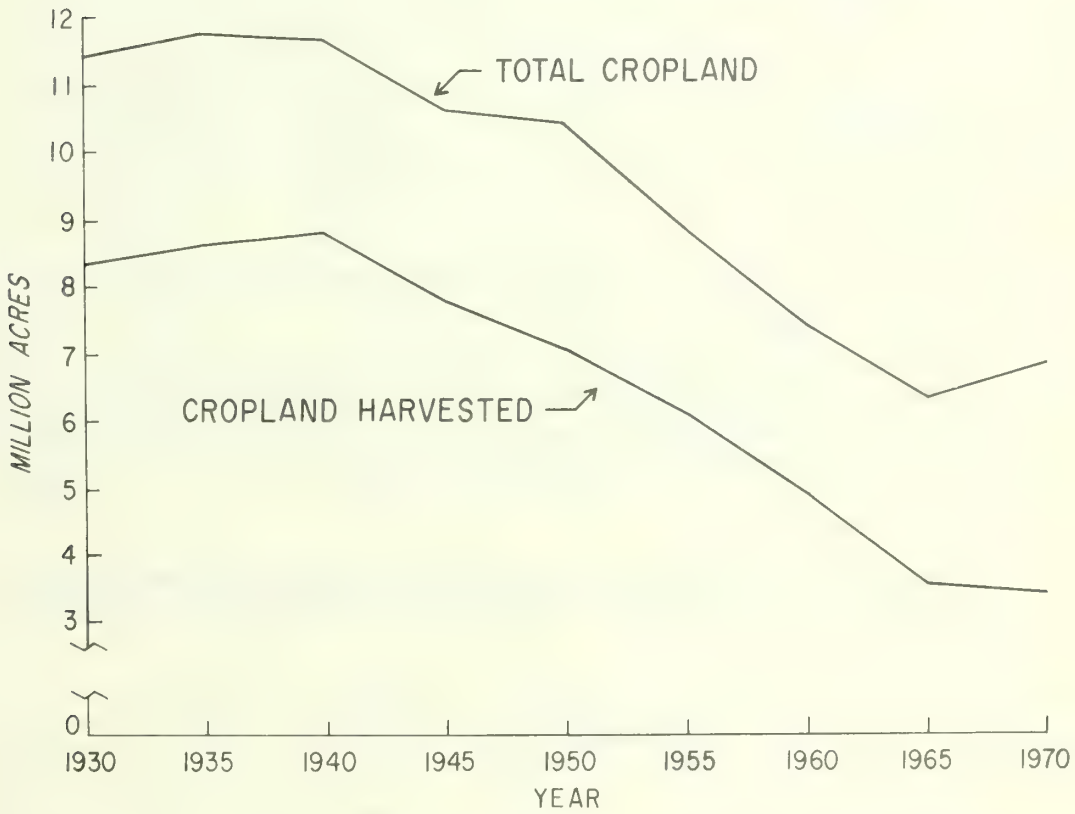

Figure 4.--Since 1940 the acreage of total cropland and the acreage of cropland harvested have declined rapidly in Georgia. (Source: U.S. Census of Agriculture.)

URBANIZATION

Urbanization removes land permanently from forest production. Examples of urban uses include residential developments, highways, water impoundments, utility rights-of-way, greenbelts, parks, wildlife refuges, and forest preserves (Knight 1973). Between 1961 and 1972, 325,000 acres were made into a wildlife refuge, 215,000 acres went to new residences, 172,000 acres went to parks and greenbelts, and 222,300 acres were made into highways and rights-of-way. About 83,400 acres were for water impoundments. Most of the loss was from hardwood ecosystems. The total loss from forest land was more than 1 million acres and the loss from agriculture was about 250,000 acres (table 15).

Table 15.--Rotations of land to urban use in Georgia from 1961 to 1972

Type of land being rotated	Removed from urban	Added to urban	Net change
		- - - Thousand acres - - -	
Hardwoods	0	513.7	+513.7
Agriculture	0	250.0	+250.0
Minor pines	0	170.0	+170.0
Loblolly	0	138.6	+138.6
Slash	0	123.9	+123.9
Oak-pine	0	102.9	+102.9
Total change	0	[1]1,299.1	[1]+1,299.1

[1]Includes areas converted to water between 1961 and 1972. Thus, this value is larger than the net change shown in figure 1.

During the 11-year period the amount of land in the urban classification increased by 65 percent. This rapid rate of increase may or may not continue.

OPPORTUNITIES FOR ACTION

Our analyses suggest five actions to keep about one-third of Georgia in pine.

1. Reforest every harvested pine stand to full stocking.

The technology for achieving both natural and artificial reforestation of pine is known (Wenger and Trousdell 1958). The most important reason for the rapid rotation of pine stands to oak-pine and hardwoods is the lack of reforestation at the time of harvesting.

The data (tables 3, 4, 6, 7, 10, 11) indicate that relatively few pine stands are reforested at the time of harvest. Rather than reforesting harvested stands, most forestation efforts are directed to the conversion of oak-pine and minor pine stands and the planting of retired cropland. These investments could be more effective if they were directed toward making reforestation an essential part of the harvesting process.

2. Delay the harvest of loblolly and slash pine stands until age 30 or later.

Problems and costs associated with regeneration can be delayed somewhat by extending rotations where loblolly and slash pine now exist. It certainly seems wise to delay harvest until maximum annual yields have been realized. Maximum yield in cubic volume is achieved at about age 30 for natural and planted stands of both loblolly and slash pine (Boyce and others 1975a, 1975b). And, since mean annual increments from age 30 to 40 are larger than from age 0 to 10, consideration should be given to extending rotations beyond age 30. However, a considerable land base could be maintained and production increased by limiting all harvests to age 30 or later.

3. Reduce thinnings and related timber stand improvements in pine stands.

It is apparent that early thinning and related actions, as now used, speed the rotation of pine stands to oak-pine and hardwoods. These actions also reduce the accumulation of cubic volume. Thus, the area in pines can be better maintained and production can be increased by reducing thinnings and similar timber stand improvements in pine stands.

4. Use timber stand improvement primarily to convert oak-pine stands to pine.

For the immediate future the conversion of oak-pine stands that were formerly in the loblolly and slash pine ecosystems offers an opportunity to speed the rotation of land to pine. This is one of the most effective uses of timber stand improvement.

5. Stop converting natural stands of longleaf, shortleaf, pond, and Virginia pine to loblolly and slash pine.

Relatively small areas of the minor pines remain for conversion (table 1). Furthermore, the rapid conversion of natural stands of longleaf, shortleaf, pond, and Virginia pine to loblolly and slash pine plantations reduces the total biological potential for pine timber production in the South. Many conversion plantations that fail during the first rotation are not replanted. In the Gulf Coast and Plantation Timber Production Provinces, where most conversions are made, both loblolly and slash pine plantations have high losses to fusiform rust (Powers and others 1975). Without reforestation after the first conversion these areas are lost to the future production of native pine timber.

Had these five actions been in effect from 1961 to 1972, the total acres of pine could have increased about 786,000 acres. Estimates of the combined effects of these actions on individual land use classes are shown in table 16. For these estimates the rate of natural succession from pine

Table 16.--Actual land area, net change, and rotation for seven types of land use in Georgia in 1961 and 1972 (from table 1), and estimates of what would have occurred had the five recommendations been followed throughout the period

(In thousand of acres)

ACTUAL

Type of land use	1961 area	1972 area	Net change	Rotation	
				Removed	Added
Loblolly pine	5,077.8	5,014.9	-62.9	1,556.1	1,493.2
Slash pine	4,102.4	4,527.6	+425.2	1,101.1	1,526.3
Minor pines	3,970.8	2,782.6	-1,188.2	2,036.4	848.2
Oak-pines	3,642.2	4,142.9	+500.7	2,244.7	2,745.4
Hardwoods	8,994.9	8,371.0	-623.9	2,592.6	1,968.7
Agriculture	9,466.0	9,105.4	-360.6	1,317.2	956.6
Urban	1,872.7	3,084.8	+1,212.1	0	1,212.1
Total[1]	37,126.8	37,029.2	[2]-97.6	10,848.1	10,750.5

ESTIMATED

Loblolly pine	5,077.8	5,389.2	+311.4	510.5	821.9
Slash pine	4,102.4	4,293.1	+190.7	454.9	645.6
Minor pines	3,970.8	3,439.2	-531.6	660.0	128.4
Oak-pines	3,642.2	2,872.6	-769.6	2,035.6	1,266.0
Hardwoods	8,994.9	8,844.9	-150.0	1,553.8	1,403.8
Agriculture	9,466.0	9,105.4	-360.6	1,317.2	956.6
Urban	1,872.7	3,084.8	+1,212.1	0	1,212.1
Total[1]	37,126.8	37,029.2	[2]-97.6	6,532.0	6,434.4

[1]Excludes all water areas.

[2]Reduction due to exclusion of new water areas.

to hardwoods is reduced by one-half because natural succession is apparently speeded by some kinds of timber stand improvement.

The loblolly pine data illustrate the method of calculating the rotation rates. In table 4, reforestation of every harvested stand would have kept 513,000 acres in loblolly pine. No timber stand improvement in pine would have kept another 356,500 acres in loblolly pine. Removals from loblolly pine would have included the losses to urbanization, agriculture, disturbance, and half of the natural succession. Additions to loblolly pine would have included the conversions from oak-pine and agriculture (table 3) but no conversions of hardwoods, minor pines, and slash pine. The net result could have been an increase of 311,400 acres rather than a loss of 62,900 acres (table 16).

The net increase in acres of slash pine would have been less because the minor pines, mostly longleaf, would not have been converted. More acres would have been kept in the minor pines, and the total pine area could have increased about 786,000 acres.

Oak-pine types would have declined rather than increased. If implemented, these actions would eventually reduce the area in oak-pine to a small fraction of the present total.

Fewer acres of hardwoods would have been converted.

The actions proposed do not affect land rotations in agriculture and urbanization. A continued rapid rate of urbanization may continue to reduce the total area in forest.

More effective use of the forest land for pine production can result from implementation of these five actions. About one-third of Georgia can be kept in pine for many years.

LITERATURE CITED

Anderson, Walter C.
1974. An economist's view of the pine-site hardwood problem. For. Prod. J. 24(4): 14-16.

Ashe, W. W.
1915. Loblolly or North Carolina pine. N. C. Geol. & Econ. Survey Bull. 24. 176 p. [Prepared in cooperation with USDA For. Serv.]

Boyce, Stephen G.
1951. Plant succession in thinned loblolly pine stands of a Piedmont county. M.S. thesis. N. C. State Univ., Raleigh. 61 p.

Boyce, Stephen G.
1974. Loblolly pine timber--the biological potential for the Southeast. South. Lumberman 229(2848):71-75.

Boyce, Stephen G., and Noel D. Cost
1974. Timber potentials in the wetland hardwoods. In Water resources--utilization and conservation in the environment, p. 130-151. Fort Valley State Coll., Fort Valley, Ga.

Boyce, Stephen G., Joe P. McClure, and Herbert S. Sternitzke
1975a. Biological potential for the loblolly pine ecosystem east of the Mississippi River, 27 p. USDA For. Serv. Res. Pap. SE-142. Southeast. For. Exp. Stn., Asheville, N. C.

Boyce, Stephen G., Joe P. McClure, and Herbert S. Sternitzke
1975b. Biological potential for the slash pine ecosystem. USDA For. Serv. Res. Pap. SE-141, 29 p. Southeast. For. Exp. Stn., Asheville, N. C.

Brender, E. V.
1974. Impact of past land use on the lower Piedmont forest. J. For. 72:34-36.

Frey, H. Thomas, and Henry W. Dill, Jr.
1971. Land use change in the Southern Mississippi Alluvial Valley, 1950-69--an analysis based on remote sensing. USDA Econ. Res. Serv. Agric. Econ. Rep. 215, 26 p.

Knight, Herbert A.
1973. Land-use changes which affected Georgia's forest land, 1961-1972. USDA For. Serv. Res. Note SE-189, 4 p. Southeast. For. Exp. Stn., Asheville, N. C.

Knight, Herbert A., and Joe P. McClure
1974. Georgia's timber, 1972. USDA For. Serv. Resour. Bull. SE-27, 48 p. Southeast. For. Exp. Stn., Asheville, N. C.

Larson, Robert W.
1957. The timber supply situation in Georgia. USDA For. Serv. For. Resour. Rep. 12, 51 p. Washington, D. C.

Larson, Robert W., and Benjamin Spada
1963. Georgia's timber. U.S. For. Serv. Resour. Bull. SE-1, 39 p. Southeast. For. Exp. Stn., Asheville, N. C.

Murphy, P. A., and H. A. Knight
1974. Hardwood resources on southern pine sites. For. Prod. J. 24(2):13-16.

Nelson, Thomas C.
1957. The original forests of the Georgia Piedmont. Ecology 38:390-397.

Plummer, Gayther L.
[n.d.] 18th century forests in Georgia. Bull. Ga. Acad. Sci. 33:1-19.

Powers, H. A., J. P. McClure, H. A. Knight, and G. F. Dutrow
1975. Fusiform rust: Forest Survey incidence data and financial impact in the South. USDA For. Serv. Res. Pap. SE-127, 16 p. Southeast. For. Exp. Stn., Asheville, N. C.

Schultz, Robert P.
1975. Intensive culture of southern pines: maximum yields on short rotations. Iowa State J. Res. 49(3):325-337.

Spillers, A. R., and I. F. Eldredge
1943. Georgia forest resources and industries. USDA Misc. Publ. 501, 70 p. South. For. Exp. Stn., New Orleans, La.

Wahlenberg, W. G.
1960. Loblolly pine. Duke Univ. Sch. For., Durham, N. C. 603 p.

Wenger, Karl F., and Kenneth B. Trousdell
1958. Natural regeneration of loblolly pine in the South Atlantic Coastal Plain. USDA For. Serv. Prod. Res. Rep. 13, 78 p.

Whisler, Frank D.
1974. Management of wetlands for agricultural production, water storage and recycling: alternative uses. In Water resources--utilization and conservation in the environment, p. 107-129. Fort Valley State Coll., Fort Valley, Ga.

Wooten, Hugh H., and James R. Anderson
1957. Major uses of land in the United States--summary for 1954. USDA Agric. Res. Serv. Agric. Inf. Bull. 168, 102 p.

Yoho, James G., George F. Dutrow, and James E. Moak
1969. What it costs to practice forestry. For. Farmer 28(11):20-24, 26, 28, 30-31.

Boyce, Stephen G., and Joe P. McClure
1975. How to keep one-third of Georgia in pine. USDA For. Serv. Res. Pap. SE-144, 23 p. Southeast. For. Exp. Stn., Asheville, N. C.

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USDA Forest Service Research Paper SE-145 February 1976

Cone and Seed Production in Slash Pine: Effects of Tree Dimensions and Climatic Factors

by
R. J. Varnell

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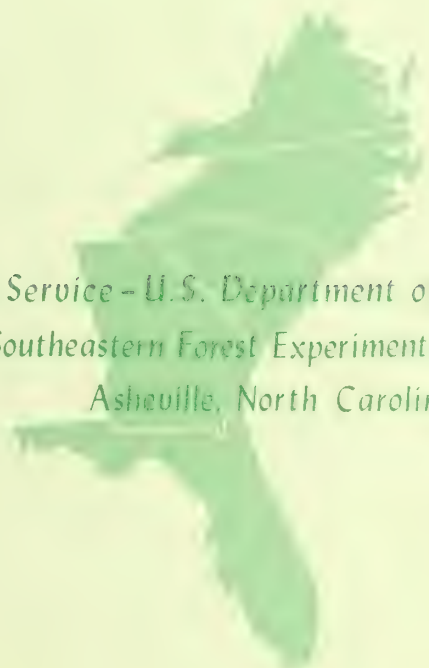

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Cone and Seed Production in Slash Pine: Effects of Tree Dimensions and Climatic Factors

by

R. J. Varnell[1]

Of the many endogenous and environmental factors which affect cone and seed production in forest trees, some have greater regulatory effects than others. The factors to which a regulatory role is most often assigned include availability of moisture in certain parts of the year, temperature in certain months, tree size, tree age, and genotype as expressed by previous fecundity (Matthews 1963; Brøndbo 1970). A study of these factors in slash pine (Pinus elliottii Engelm. var. elliottii) in the Southeastern United States is reported here.

MATERIALS AND METHODS

Twenty trees near Olustee, Florida, were initially selected for study in 1961. Data from these trees were used to evaluate the effects of climatic factors. Sixty-six trees were added to the study between 1962 and 1964 to better evaluate the effects of tree dimensions and endogenous cycles in cone and seed production. All trees used in the study were selected from natural stands and resembled seed-orchard trees in that they were open-grown with full crowns and were sexually mature. The trees ranged in age from 15 to 33 years when selected for study.

All trees were growing on Leon fine-sand soils, which are low in nutrients and organic matter. Site index in the study area is approximately 65 feet at age 25.

Data were taken annually through 1969 from each tree. These measurements included d.b.h., tree height, percentage of live crown, number of first-year conelets in April, number of mature cones in August, total number of seed per cone, and percentage of sound seed. Tree averages and ranges for each measurement are shown in table 1.

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Table 1.--Averages and ranges for data taken annually for 9 years from each slash pine tree

Measurement	Average per tree	Ranges of tree means
D.b.h. (in)	16.2	9.5-28.0
Height (ft)	59.4	41-90
Live crown (percent)	35.1	19-55
Conelet yield (No.)	58.1	0-310
Cone yield (No.)	32.7	0-222
Total seed per cone (No.)	52.9	0-117
Sound seed (percent)	64.7	0-93

Diameter was measured with a tape; nails were driven into the trunks to ensure that successive measurements were made at the same place on the trunks each year. Tree height and percentage of live crown were determined with an Abney level.

Conelets and cones were counted with 7 x 50 binoculars from a point 100 feet south of each tree. For a detailed description and assessment of this method of counting cones, see Hoekstra (1960) and Webb and Hunt (1965). Binocular counts of conelets and cones were adjusted to whole-tree estimates by using multiplication factors determined for slash pine in this area by Hoekstra (1960). The factors are 2.4 for conelets and 2.2 for cones.

Total seed and percentage of sound seed were determined by extracting and winnowing seed from a 10-cone sample from each tree annually. Germination tests showed that winnowing effectively separated sound from empty seed.

Causes of conelet mortality were determined for the 1963 crop by periodically examining conelets on each of four sample branches in each of eight trees in 1963 and 1964. The extent of insect damage was determined annually from the binocular counts and when cones were harvested in the fall.

Precipitation and temperature were determined from U.S. Weather Bureau sheets of climatological data for Lake City, Florida, located 12 miles west of the study area. Feasibility of using temperature data from Weather Bureau records was confirmed by comparing daily high and low temperatures from the Lake City station with thermograph records from the study area over the period of one year. Although daily precipitation varies widely at different locations in this region, especially during the summer months, monthly averages and totals were sufficiently uniform that no adjustment of the Lake City data was necessary. Precipitation and temperature data for March through September, in 1-, 2-, and 3-month combinations, were used to determine relationships with conelet, cone, and seed yields.

Effects of temperature on the attainment of maximum receptivity to pollination by young conelets were analyzed according to Lindsey and Newman's (1956) duration-summation method for heat sums. Dates on which conelets attained maximum receptivity (conelet developmental stage 3, according to Snow and others 1943) were averaged by years from 12 annual records of controlled pollinations in many trees in the Olustee area.

Of the several relationships between precipitation, temperature, or tree dimensions and conelet, cone, or seed yields, three were statistically analyzed. These relationships were (1) June precipitation and conelet yields, (2) temperature and attainment of maximum receptivity to pollination in young conelets, and (3) fecundity of individual trees in successive years.

RESULTS AND DISCUSSION

Tree Dimensions

There was a weak tendency for average conelet and cone production to increase with increasing tree or crown size and tree age, but trees averaging the same number of conelets or cones for the study period varied considerably in average d.b.h., height, and percentage of live crown. Because the trees did not vary greatly in age and most of them had been bearing cones for many years when the study began, absence of a strong age effect in the study was not surprising. These results suggest that cone production in mature, open-grown slash pine is not as strongly related to tree size, especially d.b.h., as is the case in longleaf (*P. palustris* Mill.) and loblolly (*P. taeda* L.) pines (Allen 1953; Grano 1957).

Conelet Production

Average annual conelet production varied according to precipitation in June one year earlier (fig. 1). The regression equation, for which $r^2 = 0.38$ and $P = 0.08$, was

$$\text{Number of conelets} = 23.90 + 8.72\ (\text{June rainfall})$$

Similar associations have been observed for rainfall in February and March and conelet production in slash pine in Louisiana (Shoulders 1973), for April-July rainfall and conelet production in longleaf pine (Shoulders 1967), for May-July rainfall and cone production 2 years later in loblolly pine (Wenger 1957), and for March-May rainfall and seed production 2 years later in loblolly pine (Grano 1973). In these previous studies, summer rainfall generally was detrimental (Shoulders 1967, 1973; Grano 1973). In a seed orchard of loblolly pine, irrigation from April through June stimulated conelet production, and irrigation from July through September reduced it (Dewers and Moehring 1970). In the present study, precipitation in months other than June and in combinations of these months showed no relationship to conelet production.

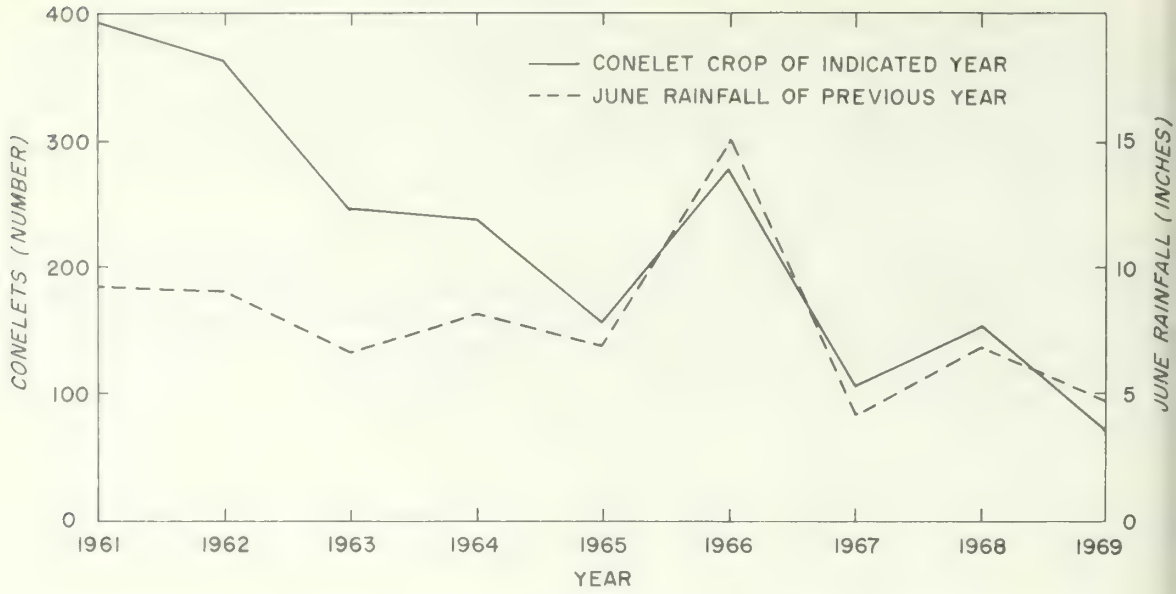

Figure 1.--Relationship between June rainfall and average conelet production per tree one year later in slash pine.

This study suggests that rainfall in June is critical for conelet initiation, which occurs in July in slash pine around Olustee (Mergen and Koerting 1957). The relatively short period of critical rainfall observed here contrasts with that observed in previous studies (Wenger 1957; Shoulders 1967, 1973; Grano 1973). This contrast might be explained by the fact that precipitation in north Florida is abundant and fairly evenly distributed from March through September, except for occasional droughty periods of short duration. Thus, moisture may be a limiting factor in conelet initiation for no more than several consecutive days at any one time during the spring and early summer in this area.

The apparent difference between the duration of critical rainfall observed in this study and in those cited above would be resolved if a more sensitive investigation revealed that conelet production in this area is influenced by precipitation in additional months. On the other hand, if the duration of critical rainfall in this area is indeed restricted to the month of June, then physiological processes which are capable of changing quickly in response to environmental fluctuations must be involved. If so, it is intuitively appealing to consider physiological processes involving growth regulators. Furthermore, the short-lived drought typically occurring in May or the first part of June often is sufficiently intense to sharply reduce moisture content in the upper strata of the sandy soils in this area. Thus, the low moisture regime in the upper soil layers would for a short time seriously limit the availability of nutrients in this soil region and, therefore, the utilization patterns of nutrients and other substances in the tree. These effects within the tree could be mediated by the distribution of growth regulators between roots and shoots.

Annual variation in June rainfall partially accounts for the tendency of the number of conelets per tree to decline throughout the study (fig. 1). This decline could not be accounted for by compensatory changes in crown length or canopy closure, the addition of trees with lower yields, or human error. How-

ever, host-predator relationships in which the degree of predation depends on the density of the host population (Manten 1965; Knipling and Gilmore 1971) might help explain why conelet yields per tree declined whereas cone yields did not (fig. 2). According to these relationships, losses to predators are proportionally greater when the host population is large. Thus, surviving host populations tend to be relatively constant in size. In the present study, developing conelets constitute the host population. Detailed records of the 1963 conelet crop showed that insects (Dioryctria sp.) were very destructive. Squirrels accounted for only a small fraction of the crop in August, just as cones were ripening. Most of the conelets were lost to unknown causes during the period from August to February between the first and second growing seasons.

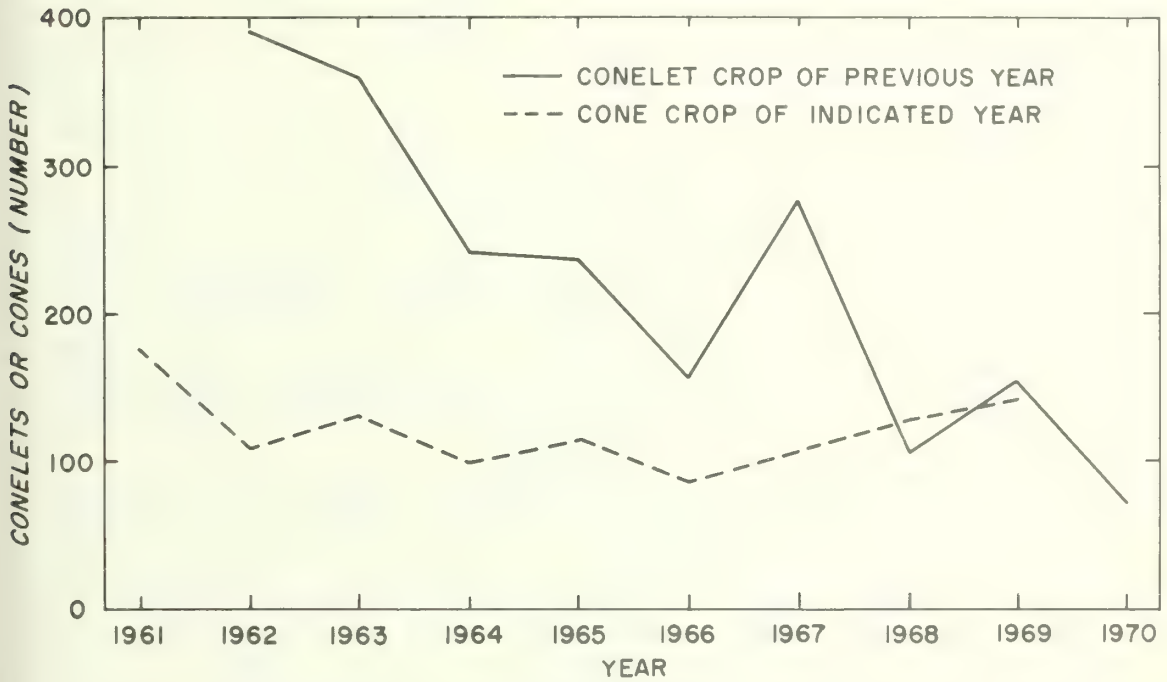

Figure 2.--Average number of conelets and cones per tree by year in slash pine.

Temperature did not affect average annual production of conelets, but the date on which young conelets became maximally receptive to pollination was dependent upon temperature (fig. 3). The results show that the date of maximum receptivity occurs earlier in warm winters than in cool winters, as would be expected if conelet development is a physiologically regulated process. Similar relationships between temperature and the development of pollen and catkins have been observed in longleaf pine (Boyer 1973; Boyer and Woods 1973). Normal development leading to maximum receptivity of slash pine conelets requires about 420 degree-hours above an approximate threshold of 40° F, according to heat-sum analysis. Hence, development requires about 25 days of average temperatures in the Lake City-Olustee area. It is unfortunate that there is no way at present to estimate beforehand the starting date of this developmental period.

The fact that the temperature-receptivity relationship was based on averages must be emphasized. Dr. R. E. Goddard (Univ. Fla., personal communication) has pointed out that some trees or clones attain maximum receptivity consistently

earlier than most, while some are typically late. Moreover, in this area, a warm December and January, while advancing the average date of maximum receptivity, results in a longer period between the time the early trees attain maximum receptivity and the time the last ones do. A cold season, on the other hand, delays attainment of receptivity and shortens the period between the time the first and last trees are maximally receptive.

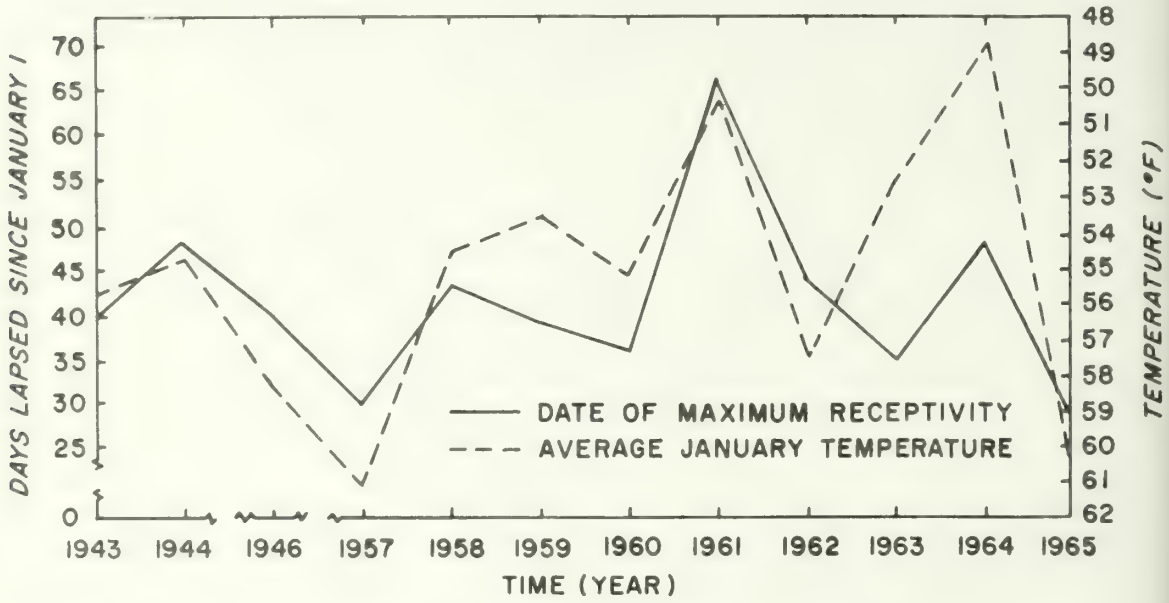

Figure 3.--Relationship of average January temperature to number of days lapsed since January 1 before newly emerged conelets attained maximum receptivity to pollination in slash pine.

Cone Production

There was no evidence of a relationship between number of cones per tree and climatic factors in slash pine. Unlike loblolly pine (Wenger 1957), in slash pine the effect of rainfall on conelet production did not extend to cone production because of the independent variation of conelet survival. Cone production is, of course, a function of conelet production 18 months earlier and of conelet survival during the ensuing period until cone maturation. The proportion of conelets surviving to maturity varied widely among conelet crops (fig. 2). Approximately 33 percent of the 1961 crop survived to maturity in 1962. Eighty percent of the 1965 crop of conelets survived to 1966, and survival of the 1967 and 1968 crops to 1968 and 1969 must have been close to 100 percent. The greater number of cones per tree in 1968 than of conelets recorded in 1967 probably was due to an error in counting those conelets which were hard to see. A few trees were found to be especially susceptible to attack by cone insects. Of these trees, some never produced a mature cone during the study, although they bore conelets almost every year. These results parallel closely those reported for shortleaf pine (P. echinata Mill.) in Virginia (Bramlett 1972).

Seed Production

No effect of precipitation, temperature, or tree dimensions on seed production was observed. Although total seed yield is correlated with cone production, average number of seed per cone and percentage of sound seed were not correlated with average number of cones per tree. Some of the variation among trees was caused by differential insect predation. It was common to find large tree-to-tree differences in amount of insect damage. These differences were probably genetically based. Laspeyresia sp. seedworms (Merkel and Ebel 1961) and two sucking insects (DeBarr 1967) reduce the proportion of sound seed in slash pine without seriously damaging the cones. Control of insects would obviously increase both cone and seed yields.

Fecundity

Despite the annual variation in conelet, cone, and seed production within trees, fecundity of individual trees was the most consistent factor observed. Some trees produced large conelet crops almost every year; a few others were consistently unproductive. The intraclass correlation estimating repeatability of conelet production in individual trees was 0.68. Similar results have been reported previously for slash pine (Goddard 1964; Shoulders 1973) and for longleaf pine (Shoulders 1967) and loblolly pine (Wenger 1957), as well as for other species. Trees producing large numbers of conelets usually matured large numbers of cones annually, but they did not necessarily have the most seed per cone or the highest percentage of sound seed.

Variation in fecundity among trees clearly suggests that endogenous factors, of which some presumably are inherited (Varnell and others 1967), influence cone and seed production in slash pine. Shoulders (1967, 1973) came to the same conclusion about flowering in longleaf pine and slash pine in Louisiana. Production of relatively large or small crops in alternate years (fig. 2) indicated internal regulation of conelet and cone production in slash pine, a process also suggested to explain cyclic seed production in loblolly pine (Wenger 1957; Grano 1973). But the factors, endogenous or otherwise, which are involved in conelet and cone production are not the same as those which influence the number of seed per cone and percentage of sound seed in slash pine. The fact that conelet and cone production were not related to number of seed per cone and percentage of sound seed has been mentioned. Even the number of seed per cone and the proportion which are sound may be influenced by different factors, for they were not correlated with each other in this study.

It seems obvious from this study that precipitation, temperature, and tree dimensions play at best only minor roles in regulating cone and seed production in open-grown, sexually mature slash pine. The relative importance of endogenous factors in slash pine emphasizes the role of physiology and inheritance in cone and seed production. Future research should be directed to the study of the physiology of flowering in seed orchards, where clonal material would provide the genetic control which was absent in the present study. The information obtained would be directly applicable to the conditions under which improved seed is being produced commercially.

SUMMARY

The results of this study of slash pine in north central Florida can be summarized as follows:

1. Precipitation in June was positively associated with number of conelets produced the following spring.

2. Rate of development of newly emerged conelets depended on temperature; about 420 degree-hours with a 40° F threshold were required to reach the stage of maximum receptivity for pollination.

3. Precipitation, temperature, and tree dimensions had no detectable influence on cone production, the number of seed per cone, or percentage of sound seed.

4. Cone and seed production were influenced most by insect predation and endogenous factors not reflected in tree dimensions.

5. Previous fecundity was the best indicator for predicting conelet, cone, and seed production.

6. Cone production, number of seed per cone, and percentage of sound seed were not correlated with each other and may be regulated by different factors.

ACKNOWLEDGMENTS

This study was planned and installed by William C. Asher. I thank Johnie K. Dobson, Jr., for his help in collecting data and E. Carlyle Franklin for assistance with the manuscript.

LITERATURE CITED

Allen, R. M.
1953. Release and fertilization stimulate longleaf pine crop. J. For. 51:827.

Boyer, W. D.
1973. Air temperature, heat sums, and pollen shedding phenology of longleaf pine. Ecology 54:420-426.

Boyer, W. D., and F. W. Woods
1973. Date of pollen shedding by longleaf pine advanced by increased temperatures at strobili. For. Sci. 19:315-318.

Bramlett, D. L.
1972. Cone crop development records for six years in shortleaf pine. For. Sci. 18:31-33.

Brøndbo, P.
1970. Flowering in forest trees: A review. For. Comm. Lond. Transl. 434, 11 p.

DeBarr, G. L.
1967. Two new sucking insect pests of seed in southern pine seed orchards. U.S. For. Serv. Res. Note SE-78, 3 p. Southeast. For. Exp. Stn., Asheville, N. C.

Dewers, R. S., and D. M. Moehring
1970. Effect of soil water stress on initiation of ovulate primordia in loblolly pine. For. Sci. 16:219-221.

Goddard, R. E.
1964. The frequency and abundance of flowering in a young slash pine orchard. Silvae Genet. 13:165-192.

Grano, C. X.
1957. Indices to potential cone production of loblolly pine. J. For. 55:890-891.

Grano, C. X.
1973. Loblolly pine fecundity in south Arkansas. USDA For. Serv. Res. Note SO-159, 7 p. South. For. Exp. Stn., New Orleans, La.

Hoekstra, P. E.
1960. Counting cones on standing slash pine. USDA For. Serv. Southeast. For. Exp. Stn. Res. Notes 151, 2 p. Asheville, N. C.

Knipling, E. E., and J. E. Gilmore
1971. Population density relationships between hymenopterous parasites and their aphid hosts. A theoretical study. U.S. Dep. Agric., Agric. Res. Serv. Tech. Bull. 1428, 34 p.

Lindsey, A. A., and J. E. Newman
1956. Use of official weather data in springtime-temperature analysis of an Indiana phenological record. Ecology 37:812-823.

Manten, H. W.
1965. Parasites of fishes as biological indicators of recent and ancient conditions. In James E. McCauley, ed., Host-parasite relationships. 26th Annu. Biol. Colloq. Proc. 1965:59-71. Oreg. State Univ. Press, Corvallis.

Matthews, J. D.
1963. Factors affecting the production of seed by forest trees. For. Abstr. 24:i-xiii.

Mergen, F., and L. E. Koerting
1957. Initiation and development of flower primordia in slash pine. For. Sci. 3:145-155.

Merkel, E. P., and B. H. Ebel
1961. Cone and seed insects and their control. Sixth South. Conf. For. Tree Improv. Proc. 1961:137-141.

Shoulders, E.
1967. Fertilizer application, inherent fruitfulness, and rainfall affect flowering of longleaf pine. For. Sci. 13:376-383.

Shoulders, E.
1973. Rainfall influences female flowering of slash pine. USDA For. Serv. Res. Note SO-150, 7 p. South. For. Exp. Stn., New Orleans, La.

Snow, A. G., Jr., K. W. Dorman, and C. S. Schopmeyer
1943. Developmental stages of female strobili in slash pine. J. For. 41:922-923.

Varnell, R. J., A. E. Squillace, and G. W. Bengtson
1967. Variation and heritability of fruitfulness in slash pine. Silvae Genet. 16:121-148.

Webb, C. D., and D. L. Hunt
1965. Seed crop estimation in a slash pine seed production area. Ga. For. Res. Counc. Res. Pap. 28, 5 p.

Wenger, K. F.
1957. Annual variation in the seed crops of loblolly pine. J. For. 55:567-569.

Varnell, R. J.
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USDA Forest Service Research Paper SE-146 April 1976

Biomass of Shortleaf Pine in a Natural Sawtimber Stand in Northern Mississippi

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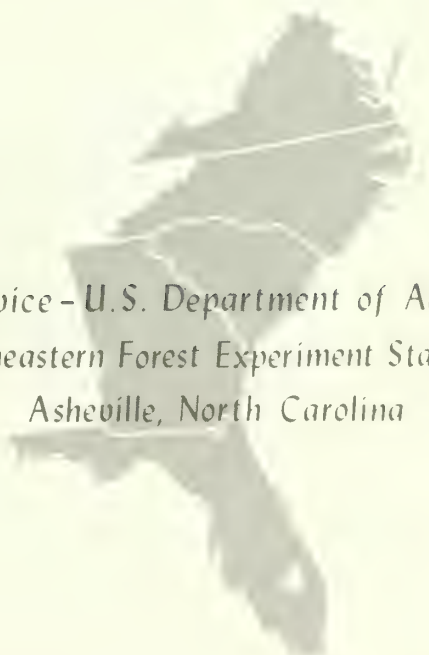
by

Alexander Clark III
and
Michael A. Taras



Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Conversion factors: English to metric

Multiply		By		To Obtain
Inches	x	2.540	=	centimeters
Feet	x	.3048	=	meters
Pounds	x	.4536	=	kilograms
Cubic feet	x	.02832	=	cubic meters
Pounds per cubic foot	x	16.02	=	kilograms per cubic meter

All English units of measure in this report can be converted to metric units by multiplying by the appropriate conversion factor listed above.

Biomass of Shortleaf Pine in a Natural Sawtimber Stand in Northern Mississippi[1]

by

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Abstract.--Shortleaf pine trees 6 to 20 inches d.b.h. were selected from a natural, uneven-aged sawtimber stand in northern Mississippi to determine weight and volume of aboveground biomass. On the average, 84 percent of the dry weight of the total tree was wood, 12 percent was bark, and 4 percent was needles. The average tree sampled had 88 percent of its wood in the stem and 12 percent in the crown. Trends in biomass proportions are discussed; and specific gravity, moisture content, and green weight per cubic foot are presented for the total tree and its components. Tables developed with regression equations predict weight and volume of the total tree and its components by d.b.h. and total height classes.

Keywords: Pinus echinata Mill., weight, volume, prediction equations, component proportions.

Utilization of the total tree is now a reality. Pulpwood trees and upper stems and tops of sawtimber trees are being chipped in the field for use in paper and reconstituted board products. With the advent of total tree harvesting, estimates of the volume or weight of the merchantable stem no longer provide sufficient information for making decisions on the utilization of forest resources. Wood-using industries, timber owners, and researchers need data on the weight and volume of aboveground tree biomass. This paper on biomass of natural stands of shortleaf pine (Pinus echinata Mill.) is the second in a series of such reports, the first of which dealt with loblolly pine (P. taeda L.).[2]

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[1]This study was conducted by the Southeastern Forest Experiment Station in cooperation with and through the financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System. Field personnel were provided by the Holly Springs District of the Holly Springs National Forest.

[2]Taras, Michael A., and Alexander Clark III. 1975. Aboveground biomass of loblolly pine in a natural, uneven-aged sawtimber stand in central Alabama. Tappi 58(2):103-105.

The present paper discusses green and dry weight of aboveground biomass of commercial-size shortleaf pines in a natural, uneven-aged sawtimber stand in northern Mississippi. Proportion of tree biomass in wood, bark, and needles is discussed on a weight basis and compared to biomass on a volume basis. Equations are presented for predicting weight and volume of the total tree and its components (wood, bark, needles, main stem, branches, and crown). Wood and bark specific gravity, moisture content, and green weight per cubic foot are presented for the total tree and its component parts. Total tree in this study is synonymous with full tree as defined by Keays;[3] the term refers only to aboveground portions and does not include stump and roots.

PROCEDURE

FIELD

A stratified random sample of 34 trees was selected from a natural, close uneven-aged stand of shortleaf pine sawtimber on the Holly Springs National Forest in northern Mississippi. Site index (age 50) averaged 70. Four to six trees from each even-inch d.b.h. class from 6 to 18 inches and one tree from the inch class were selected. The sample trees had an average d.b.h. of 12.3 inches and an average total height of 72 feet. Means and ranges of tree measurements are shown in table 1.

Table 1.--Means and ranges of measurements of shortleaf pines in each d.b.h. class sampled

D.b.h. class (inches)	Sample trees	D.b.h.		Total height		Merchantable height[1/]		Age		Form class	
		Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
	Number	Inches		Feet				Years			
6	4	6.2	6.1- 6.3	49	48-51	--	--	30	28- 35	--	--
8	4	8.1	7.7- 8.3	56	52-58	10	8-14	32	29- 36	64	60-68
10	6	10.1	9.8-10.5	71	63-83	40	34-50	65	35- 83	78	74-80
12	5	12.0	11.8-12.2	76	74-78	50	46-54	86	82- 95	82	78-86
14	5	14.0	13.6-14.4	77	75-79	50	46-54	89	79- 93	82	76-85
16	5	16.0	15.6-16.3	81	77-86	55	48-60	84	79- 89	82	80-86
18	4	18.1	17.6-18.8	84	81-87	48	42-54	82	80- 85	81	79-84
20	1	19.7	--	83	--	54	--	110	--	75	--
All classes	34	12.3	6.1-19.7	72	48-87	39	10-60	70	28-110	77	60-86

[1/] Height to 6-inch d.i.b. or merchantable top.

[3] Keays, J. L. 1974. Full-tree and complete-tree utilization for pulp and paper. For. Prod. J. 24(11):13-16.

After felling and limbing, the main stem of each tree was bucked into merchantable saw logs and pulpwood. Saw logs 8 to 16 feet long were cut from the main stem to a 6-inch d.i.b. or merchantable top. Because large knots and branches prevented the stems of most large trees from being merchantable as saw logs to a 6-inch top, saw log stem top diameter averaged 8.4 inches. All material between the saw-log merchantable top and the 2-inch top was classed as pulpwood. The crown was cut up and separated into four categories: (1) large branches (≥ 2.0 inches d.o.b.), (2) medium branches (≥ 0.6 and ≤ 1.9 inches d.o.b.), (3) small branches (≤ 0.5 inches d.o.b.), and (4) needles. The tip of the stem (2 inches d.i.b. to top) was included as branch material in the analysis. All crown material and pulpwood were weighed to the nearest 0.25 pound. Saw logs were weighed individually to the nearest pound.

Moisture content and specific gravity of wood and bark were determined from disks removed from the butt of each tree, at each saw log bucking point, at the points where d.i.b. measured 4 and 2 inches, and from branches randomly selected from each branch category. A sample of needles was selected for determination of needle moisture content. The disks were weighed and calipered with and without bark immediately after being sawed. A representative sample of bark and wood was removed from each disk, weighed, and sealed in a polyethylene bag for laboratory analysis.

LABORATORY

Specific gravity was computed on a green volume and ovendry basis. Samples used for determining moisture content were dried to a constant weight at 103° C, and their moisture content was computed on an ovendry basis. Percentage of bark was determined on a weight basis from cross-sectional samples. Weighted values for moisture content, specific gravity, and percentage of bark in the stem, branches, and total tree were calculated by weighting disk values in proportion to the volume of the component they represented. Weighted values for moisture content were used to convert component green weight to ovendry weight.

The following equation was used to calculate green weight per cubic foot separately for wood and bark on the basis of the weighted values for specific gravity and moisture content:

$$\text{Green weight per cubic foot} = \left(1 + \frac{\text{weighted moisture content in percent}}{100}\right) \times (62.4 \times \text{weighted specific gravity}) \quad (1)$$

The green cubic foot volume of wood and bark was computed by dividing component weight by the component's green weight per cubic foot. Green cubic foot volume of wood and bark combined was computed by adding green volume of wood to the green volume of bark.

ANALYSIS

Simple linear regression equations for predicting green and dry weight of wood, bark, and needles in the total tree and its components were developed with d.b.h., total height, merchantable height, crown length, crown ratio, and form class as the independent variables. Equations were also developed to predict green cubic foot volume of wood and bark, separately and combined.

The best independent variables examined were d.b.h. and total height. Thus, tree and component weights and volumes were estimated with the equation

$$Y = b_0 + b_1 D^2 Th + e \qquad (2)$$

where: Y = weight or volume of component,
D = d.b.h. in inches,
Th = total tree height in feet,
e = experimental error.

Grouping of the data into $D^2 Th$ classes indicated that the variance of Y increased with increasing $D^2 Th$. Thus, a logarithmic transformation was used to make the variance more nearly homogeneous and meet this basic assumption of regression analysis. The final form of the equation used to predict weight and volume of the total tree and each component sampled was

$$\text{Log}_{10} Y = b_0 + b_1 \text{Log}_{10} (D^2 Th) \qquad (3)$$

RESULTS

TOTAL TREE BIOMASS

Green and dry weight of the total tree and proportion of tree weight in wood, bark, and needles are shown in table 2. Green weight of the total tree ranged from 292 pounds for 6-inch trees to 6,146 pounds for a 20-inch tree. On the average, the trees sampled had 84 percent of their dry weight in wood and 12 percent in bark. The proportion of tree weight in wood increased and the proportion in bark decreased as tree size increased from 6 to 10 inches d.b.h. and then remained relatively constant in trees 10 inches d.b.h. and larger. The proportion of tree weight in needles did not change consistently with tree size and averaged 4 percent. Because moisture content of green and dry components differed, component proportions also differed slightly when computed on green and dry weight bases.

When the trees were viewed as being composed of stem and crown, the proportion of the tree weight in stem material decreased and the proportion in crown material (branches plus needles) increased with increasing tree size (table 3). The proportion of tree dry weight in crown material ranged from 13 percent in small trees to 22 percent in large trees and averaged 18 percent. This increase in proportion of crown material was due to an increase in proportion of branch material and not to an increase in proportion of needles.

Table 2.--Average green and dry weight of the total tree and proportion of the tree in wood, bark, and needles for shortleaf pines 6 to 20 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree green weight	Tree component proportions (green)			Total tree dry weight	Tree component proportions (dry)		
				Wood	Bark	Needles		Wood	Bark	Needles
	Feet	Number	Pounds	- - - Percent - - -			Pounds	- - - Percent - - -		
6	49	4	292	81	13	6	138	80	15	5
8	56	4	628	82	13	5	298	81	15	4
10	71	6	1,243	85	11	4	624	84	13	3
12	76	5	2,027	85	10	5	996	84	12	4
14	77	5	3,034	85	10	5	1,492	85	11	4
16	81	5	4,273	86	9	5	2,029	85	11	4
18	84	4	5,770	86	10	4	2,740	84	12	4
20	83	1	6,146	84	11	5	2,882	82	14	4
Average	--	--	2,560	85	10	5	1,233	84	12	4

Table 3.--Average green and dry weight of the total tree and proportion of the tree in main stem[1/] and crown (branches and needles) for shortleaf pines 6 to 20 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree green weight	Tree component proportions (green)			Total tree dry weight	Tree component proportions (dry)		
				Stem	Crown			Stem	Crown	
					Branches	Needles			Branches	Needles
	Feet	Number	Pounds	- - - Percent - - -			Pounds	- - - Percent - - -		
6	49	4	292	85	9	6	138	87	8	5
8	56	4	628	85	10	5	298	86	10	4
10	71	6	1,243	89	7	4	624	90	7	3
12	76	5	2,027	85	10	5	996	86	10	4
14	77	5	3,034	82	13	5	1,492	84	12	4
16	81	5	4,273	80	15	5	2,029	81	15	4
18	84	4	5,770	79	17	4	2,740	79	17	4
20	83	1	6,146	78	17	5	2,882	78	18	4
Average	--	--	2,560	81	14	5	1,233	82	14	4

[1/] Stem material to 2-inch d.i.b. top.

The green and dry weight of all wood in the tree and the distribution of wood throughout the tree are presented in table 4. On the average, the trees had 88 percent of their dry wood weight in the main stem (to a 2-inch top) and 12 percent in branches. The proportion of wood in the main stem decreased and the proportion in branches increased as tree size increased. This increase in proportion of wood in branches was due to an increase in large branches in larger trees. As tree size increased, the proportion of wood in the pulpwood section of the tree decreased and the proportion in the saw-log section increased. On the average, the trees contained 76 percent of their dry wood in saw-log material and 12 percent in pulpwood.

Table 4.--Average green and dry weight of wood in the total tree and distribution of wood in main stem[1/] and branches for shortleaf pines 6 to 20 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree wood weight	Proportion of wood in--						
				Main stem			Branches			
				Saw log	Pulpwood	Total stem	Large	Medium	Small	All branches
	Feet	Number	Pounds	Percent						
				GREEN						
6	49	4	236	--	92	92	0	6	2	8
8	56	4	517	44	47	91	0	7	2	9
10	71	6	1,056	76	18	94	3	2	1	6
12	76	5	1,718	81	10	91	6	2	1	9
14	77	5	2,592	77	11	88	8	3	1	12
16	81	5	3,687	78	8	86	9	4	1	14
18	84	4	4,939	70	14	84	11	4	1	16
20	83	1	5,134	76	9	85	11	3	1	15
Average	--	--	2,183	74	13	87	9	3	1	13
				DRY						
6	49	4	110	--	93	93	0	5	2	7
8	56	4	241	47	45	92	0	6	2	8
10	71	6	524	79	15	94	3	2	1	6
12	76	5	840	83	9	92	5	2	1	8
14	77	5	1,266	80	9	89	8	2	1	11
16	81	5	1,735	80	6	86	9	4	1	14
18	84	4	2,296	71	13	84	11	4	1	16
20	83	1	2,352	76	8	84	12	3	1	16
Average	--	--	1,038	76	12	88	8	3	1	12

[1/] Stem material to 2-inch d.i.b. top.

The weight and distribution of bark in the tree are presented in table 5. As tree size increased, the proportion of bark in the main stem decreased and the proportion in branches increased. This increase in proportion of bark in branches was due to an increase in the proportion of large branches in larger trees. On the average, 59 percent of all dry bark in the tree was in saw-log material, 13 percent was in pulpwood, and 28 percent was in branches.

Table 5.--Average green and dry weight of bark in the total tree and distribution of bark in main stem[1/] and branches for shortleaf pines 6 to 20 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree bark weight	Proportion of bark in--						
				Main stem			Branches			
				Saw log	Pulpwood	Total stem	Large	Medium	Small	All branches
	Feet	Number	Pounds	- - - - - - - - - - - - - - - - Percent - - - - - - - - - - - - - - - -						
				GREEN						
6	49	4	38	--	81	81	0	12	7	19
8	56	4	79	39	40	79	0	14	7	21
10	71	6	136	65	17	82	5	7	6	18
12	76	5	211	62	11	73	11	9	7	27
14	77	5	303	60	9	69	15	10	6	31
16	81	5	393	57	6	63	16	13	8	37
18	84	4	593	52	12	64	18	12	6	36
20	83	1	716	55	7	62	19	8	11	38
Average	--	--	262	56	12	68	14	11	7	32
				DRY						
6	49	4	21	--	83	83	0	11	6	17
8	56	4	44	40	41	81	0	13	6	19
10	71	6	79	69	16	85	4	6	5	15
12	76	5	117	67	9	76	10	7	6	23
14	77	5	170	64	9	73	14	8	5	27
16	81	5	214	60	6	66	15	12	7	34
18	84	4	343	56	12	68	18	10	4	32
20	83	1	415	59	6	65	19	7	9	35
Average	--	--	148	59	13	72	13	9	6	28

[1/] Stem material to 2-inch d.i.b. top.

CROWN BIOMASS

When the crown was analyzed as a separate entity composed of branchwood, branchbark, and needles, the proportion of crown weight in wood increased, the proportion in needles decreased, and proportion in bark remained constant as tree size increased (table 6). On the average, 59 percent of the dry weight of the crown was in wood, 20 percent was in bark, and 21 percent was in needles.

Branches made up 7 to 18 percent of the dry weight of the total tree, depending on tree size (table 3). On the average, 12 percent of the branch weight was in small branches, 28 percent was in medium branches, and 60 percent was in large branches. These proportions in branch size varied greatly with tree size (fig. 1). The proportion of large branches increased rapidly with increasing tree size, and the proportion of medium and small branches decreased with increasing tree size. When branches were separated into wood and bark, large branches averaged 83 percent wood and 17 percent bark, medium branches averaged 72 percent wood and 28 percent bark, and small branches averaged 59 percent wood and 41 percent bark.

Table 6.--Average green and dry weight of the crown and proportion of the crown in wood, bark, and needles for shortleaf pines 6 to 20 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Crown weight (green)	Crown proportion in green--			Crown weight (dry)	Crown proportion in dry--		
				Branch-wood	Branch-bark	Needles		Branch-wood	Branch-bark	Needles
	Feet	Number	Pounds	- - - Percent - - - -			Pounds	- - - - Percent- - -		
6	49	4	44	44	16	40	19	44	20	36
8	56	4	96	49	17	34	41	49	20	31
10	71	6	138	46	18	36	62	48	20	32
12	76	5	314	51	18	31	136	51	20	29
14	77	5	547	57	18	25	245	58	19	23
16	81	5	863	61	17	22	392	61	19	20
18	84	4	1,221	63	18	19	574	64	19	17
20	83	1	1,354	58	20	22	640	59	23	18
Average	--	--	478	58	18	24	218	59	20	21

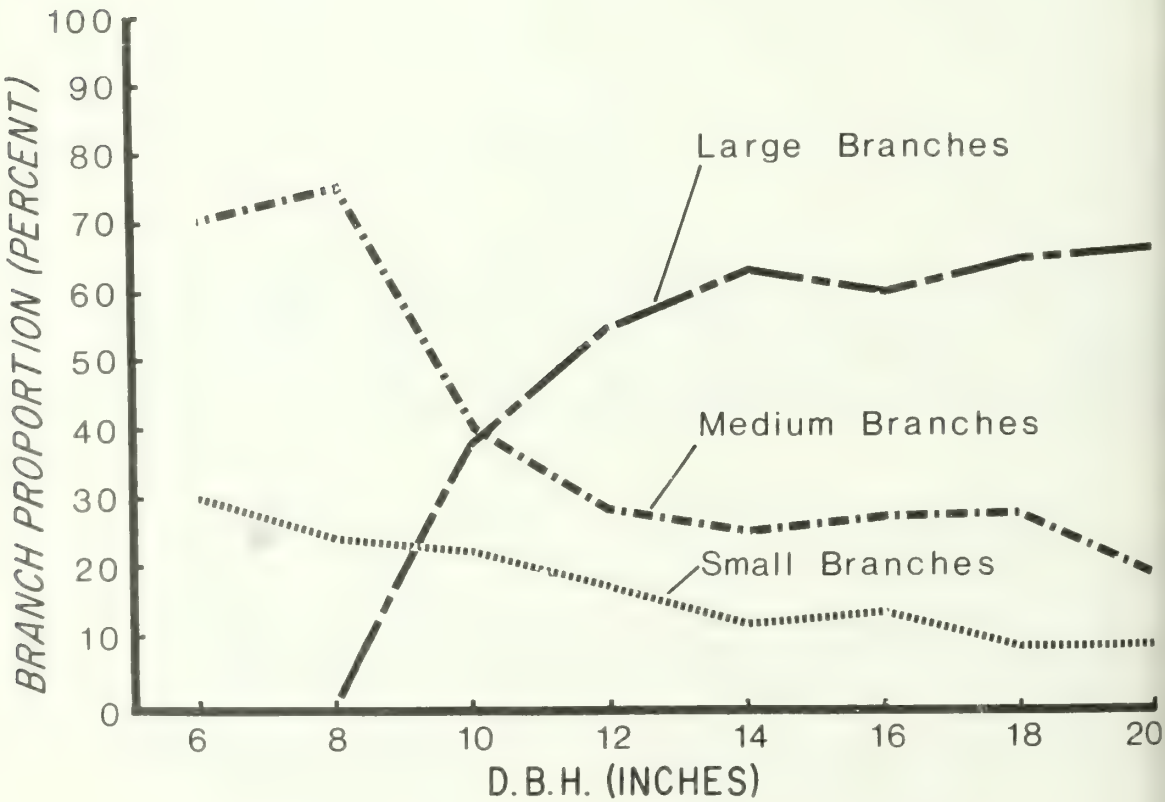

Figure 1.--Proportion of branches in crown by tree size.

MAIN STEM BIOMASS

When the main stem was analyzed separately, the proportion of stem weight in wood increased and the proportion in bark decreased as tree size increased (table 7). On the average, 89 percent of the dry weight of the stem was wood and 11 percent was bark.

Table 7.--Average green and dry weight of the stem[1/] and proportion of the stem in wood and bark for shortleaf pines 6 to 20 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Main stem weight (green)	Stem proportion in green--		Main stem weight (dry)	Stem proportion in dry--	
				Wood	Bark		Wood	Bark
	Feet	Number	Pounds	- Percent -		Pounds	- Percent -	
6	49	4	247	88	12	120	85	15
8	56	4	533	88	12	257	86	14
10	71	6	1,105	90	10	562	88	12
12	76	5	1,713	91	9	860	90	10
14	77	5	2,487	92	8	1,247	90	10
16	81	5	3,409	93	7	1,636	91	9
18	84	4	4,549	92	8	2,166	89	11
20	83	1	4,791	91	9	2,242	88	12
Average	--	--	2,082	91	9	1,014	89	11

[1/] Stem material to 2-inch d.i.b. top.

PHYSICAL PROPERTIES

Wood and bark specific gravity, moisture content, and green weight per cubic foot for the total tree and its components are presented in table 8. Wood specific gravity for the total tree averaged 0.472--the same as the average specific gravity reported for the species.[4] Wood specific gravity for pulpwood averaged 0.429, considerably lower than the values for saw logs and branches. Bark specific gravity was consistently lower than wood specific gravity, averaging 0.335 for the total tree, 0.330 for the main stem, and 0.356 for branches.

Wood moisture content averaged 109 percent for the total tree, 108 percent for the main stem, and 122 percent for the branches (table 8). Wood moisture content was considerably higher for pulpwood (134 percent) than for saw logs (102 percent).

[4] U.S. Forest Products Laboratory. 1972 (rev. 1975). Properties of major southern pines. Part I - Wood density survey, by H. E. Walgren and D. R. Schumann. Part II - Structural properties and specific gravity, by B. A. Bendtsen, R. L. Ethington, and W. L. Galligan. USDA For. Serv. Res. Pap. FPL 176-177, 76 p. U. S. For. Prod. Lab., Madison, Wis.

Table 8.--Average wood and bark specific gravity, moisture content, and green weight per cubic foot for shortleaf pine trees and tree components

Tree component	Average and standard deviation		
	Specific gravity	Moisture content	Green weight per cubic foot
		Percent	Pounds
	WOOD		
Total tree	0.472 ± .019	109 ± 10	61.5 ± 2.0
Saw log	.488 ± .028	102 ± 13	61.0 ± 2.3
Pulpwood	.429 ± .027	134 ± 16	62.6 ± 2.2
Main stem	.473 ± .020	108 ± 11	61.4 ± 2.1
Branches	.450 ± .027	122 ± 14	62.3 ± 2.7
	BARK		
Total tree	.335 ± .027	78 ± 8	37.4 ± 3.2
Saw log	.334 ± .036	67 ± 8	34.6 ± 3.7
Pulpwood	.318 ± .026	88 ± 12	37.2 ± 3.2
Main stem	.330 ± .034	71 ± 8	35.1 ± 3.3
Branches	.356 ± .028	102 ± 18	44.7 ± 2.7

On a total-tree basis, bark moisture content averaged 78 percent, considerably lower than the corresponding value for wood (table 8). Bark moisture content was also lower for saw logs (67 percent) than for pulpwood (88 percent) or branches (102 percent). This value was higher for branches than for stems because of differences in the ratio of inner to outer bark and in relative thickness of the bark.

Average wood weight per cubic foot did not vary greatly among tree components (table 8). Average green weight per cubic foot of wood was lowest for saw logs (61.0 pounds) and highest for pulpwood (62.6 pounds). Nevertheless, saw logs contained 3.4 pounds more ovendry wood per cubic foot than did pulpwood because of their higher specific gravity.

Bark was consistently lower in green weight per cubic foot than was wood (table 8). Bark green weight per cubic foot averaged 37.4 pounds for the total tree, 34.6 pounds for saw logs, 37.2 pounds for pulpwood, and 44.7 pounds for branches. Branchbark weighed more per cubic foot than did stembark because of its higher moisture content (102 vs. 71 percent) and specific gravity (0.356 vs. 0.330). Green weight per cubic foot of wood and bark combined averaged 58.7 pounds for the total tree, 58.8 pounds in the main stem, and 57.9 pounds in branch material.

VOLUME OF TREE BIOMASS

When tree biomass is considered as consisting of two major components, wood and bark, the proportions of these components differ according to whether they are computed on a weight or a volume basis. For example, on a volume basis 84 percent of the average tree sampled was wood and 16 percent was bark, but on a weight basis 88 percent of the average tree was wood and only 12 percent was bark. The 4-percent decrease in proportion of wood and corresonding increase in bark are due to differences in wood and bark weight per cubic foot. A cubic foot of green wood has a higher specific gravity and moisture content and weighs on the average 24.1 pounds more than a cubic foot of bark (table 8).

When only the wood component of a tree is analyzed, the proportions of wood contained in the various tree parts (main stem and branches) are the same whether computed on a volume or a weight basis. The proportions are constant because the wood in various parts of the tree has the same relative green weight per cubic foot. This is not the case, however, for bark. When the distribution of bark in a tree is analyzed, the proportion of bark in each component differs when calculated on a weight and a volume basis. On a volume basis, the average proportion of bark in the main stem is 4 percent less than on a weight basis. Such differences occur because a cubic foot of green branchbark is heavier than a cubic foot of green stembark (table 8).

Green weight per cubic foot of wood and bark combined does not vary significantly among tree components; thus, proportions of tree biomass in stem and branches do not differ when calculated on a weight or a volume basis. Trends in component proportions with increasing tree size are the same on either basis. Nevertheless, because component ratios can differ substantially according to the basis used for computations, users of such data should always be aware of that basis.

EQUATIONS

A series of equations was developed to predict weight and volume of the total tree and its components on the basis of the biomass of the 34 trees sampled. Equations for predicting green and dry weights of the total tree and its components are presented in table 9. Equations for predicting green cubic foot volume of the wood and bark in the total tree and its components are presented in table 10. Also included in tables 9 and 10 are the coefficients of determination and standard errors of estimate for each equation. The coefficients of determination indicate a high degree of linear association between the independent variables (D^2Th) and component weight and volume in most cases. Poorest association occurred in equations developed to predict branch weight and volume. Crown components had a higher degree of variability than other tree components.

Table 9.--Regression equations for estimating green and dry weight of aboveground biomass of natural shortleaf pine trees and tree components with d.b.h. and total height as independent variables

Weight (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]
COMPLETE TREE (INCLUDING NEEDLES)[3/]			
Green	$\text{Log}_{10} Y = -1.20938 + 1.11931 \text{ Log}_{10} D^2Th$	0.99	0.038
Dry	$\text{Log}_{10} Y = -1.52244 + 1.11886 \text{ Log}_{10} D^2Th$	.99	.031
COMPLETE TREE (EXCLUDING NEEDLES)[3/]			
Green	$\text{Log}_{10} Y = -1.25376 + 1.12517 \text{ Log}_{10} D^2Th$	.99	.038
Dry	$\text{Log}_{10} Y = -1.55499 + 1.12266 \text{ Log}_{10} D^2Th$	.99	.032
ALL WOOD IN TREE[3/]			
Green	$\text{Log}_{10} Y = -1.37140 + 1.14146 \text{ Log}_{10} D^2Th$	.99	.041
Dry	$\text{Log}_{10} Y = -1.68837 + 1.14073 \text{ Log}_{10} D^2Th$	.99	.036
ALL BARK IN TREE[3/]			
Green	$\text{Log}_{10} Y = -1.72900 + 1.00681 \text{ Log}_{10} D^2Th$	.99	.045
Dry	$\text{Log}_{10} Y = -1.99159 + 1.00983 \text{ Log}_{10} D^2Th$	.98	.050
WOOD AND BARK IN SAW-LOG PORTION OF STEM FOR TREES >9.5 INCHES D.B.H.[4/]			
Green	$\text{Log}_{10} Y = -1.27180 + 1.09858 \text{ Log}_{10} D^2Th$	.97	.042
Dry	$\text{Log}_{10} Y = -1.32372 + 1.03909 \text{ Log}_{10} D^2Th$	.97	.043
WOOD IN SAW-LOG PORTION OF STEM FOR TREES >9.5 INCHES D.B.H.[4/]			
Green	$\text{Log}_{10} Y = -1.37625 + 1.11431 \text{ Log}_{10} D^2Th$	0.97	0.045
Dry	$\text{Log}_{10} Y = -1.42052 + 1.05104 \text{ Log}_{10} D^2Th$	.96	.048
BARK IN SAW-LOG PORTION OF STEM FOR TREES > 9.5 INCHES D.B.H.[4/]			
Green	$\text{Log}_{10} Y = -1.67266 + 0.93737 \text{ Log}_{10} D^2Th$	.95	.049
Dry	$\text{Log}_{10} Y = -1.89845 + 0.93811 \text{ Log}_{10} D^2Th$	.93	.057
WOOD AND BARK IN STEM FROM STUMP TO 2-INCH D.I.B. TOP[3/]			
Green	$\text{Log}_{10} Y = -1.16592 + 1.08852 \text{ Log}_{10} D^2Th$	.99	.037
Dry	$\text{Log}_{10} Y = -1.45537 + 1.08367 \text{ Log}_{10} D^2Th$	.99	.037
WOOD IN STEM FROM STUMP TO 2-INCH D.I.B. TOP[3/]			
Green	$\text{Log}_{10} Y = -1.29252 + 1.10935 \text{ Log}_{10} D^2Th$	.99	.041
Dry	$\text{Log}_{10} Y = -1.59597 + 1.10579 \text{ Log}_{10} D^2Th$	.99	.041
BARK IN STEM FROM STUMP TO 2-INCH D.I.B. TOP[3/]			
Green	$\text{Log}_{10} Y = -1.45510 + 0.90264 \text{ Log}_{10} D^2Th$	.98	.049
Dry	$\text{Log}_{10} Y = -1.75626 + 0.91986 \text{ Log}_{10} D^2Th$	.97	.058
CROWN WEIGHT (INCLUDING BRANCHWOOD, BRANCHBARK, AND NEEDLES)[3/]			
Green	$\text{Log}_{10} Y = -2.59672 + 1.26786 \text{ Log}_{10} D^2Th$	0.94	0.125
Dry	$\text{Log}_{10} Y = -3.08921 + 1.30297 \text{ Log}_{10} D^2Th$	.94	.127

continued

Table 9.--Regression equations for estimating green and dry weight of aboveground biomass of natural shortleaf pine trees and tree components with d.b.h. and total height as independent variables (continued)

Weight (Y)	Regression equation[1]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2]
NEEDLES[3]			
Green	$\text{Log}_{10} Y = -2.11074 + 1.01076 \text{ Log}_{10} D^2Th$	.95	.086
Dry	$\text{Log}_{10} Y = -2.61282 + 1.03712 \text{ Log}_{10} D^2Th$	.95	.088
WOOD AND BARK IN ALL BRANCH MATERIAL[3]			
Green	$\text{Log}_{10} Y = -3.18256 + 1.37516 \text{ Log}_{10} D^2Th$	.92	.151
Dry	$\text{Log}_{10} Y = -3.61440 + 1.39952 \text{ Log}_{10} D^2Th$	.93	.150
WOOD IN ALL BRANCH MATERIAL[3]			
Green	$\text{Log}_{10} Y = -3.42558 + 1.40428 \text{ Log}_{10} D^2Th$	.91	.164
Dry	$\text{Log}_{10} Y = -3.91892 + 1.44117 \text{ Log}_{10} D^2Th$	.92	.162
BARK IN ALL BRANCH MATERIAL[3]			
Green	$\text{Log}_{10} Y = -3.43184 + 1.28689 \text{ Log}_{10} D^2Th$	.94	.120
Dry	$\text{Log}_{10} Y = -3.74810 + 1.29018 \text{ Log}_{10} D^2Th$	.94	.125

[1] $\text{Log}_{10} Y = b_0 + b_1 \text{ Log}_{10} D^2Th$

where: Y = weight of tree or component in pounds,
D = d.b.h. in inches,
Th = total height in feet.

[2] Standard error of estimate in Log_{10} form.
[3] Regression equations based on 34 trees 6 to 20 inches d.b.h.
[4] Regression equations based on 26 trees 10 to 20 inches d.b.h.

Table 10.--Regression equations for estimating green cubic foot volume of aboveground biomass of natural shortleaf pine trees and tree components with d.b.h. and total height as independent variables

Cubic foot volume (Y)	Regression equation[1]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2]
TOTAL TREE[3]			
Wood	$\text{Log}_{10} Y = -3.17412 + 1.14519 \text{ Log}_{10} D^2Th$	0.99	0.039
Bark	$\text{Log}_{10} Y = -3.14403 + 0.96809 \text{ Log}_{10} D^2Th$	.98	.055
Wood & bark	$\text{Log}_{10} Y = -2.95720 + 1.11202 \text{ Log}_{10} D^2Th$	.99	.032
STEM FROM STUMP TO SAW-LOG TOP FOR TREES >9.5 INCHES D.B.H.[4]			
Wood	$\text{Log}_{10} Y = -3.06942 + 1.09260 \text{ Log}_{10} D^2Th$	.96	.047
Bark	$\text{Log}_{10} Y = -3.01541 + 0.88827 \text{ Log}_{10} D^2Th$	.90	.066
Wood & bark	$\text{Log}_{10} Y = -2.87593 + 1.06190 \text{ Log}_{10} D^2Th$	.97	.038
STEM FROM STUMP TO 2-INCH D.I.B. TOP[3]			
Wood	$\text{Log}_{10} Y = -3.09675 + 1.11362 \text{ Log}_{10} D^2Th$	.99	.041
Bark	$\text{Log}_{10} Y = -2.86454 + 0.86838 \text{ Log}_{10} D^2Th$	.96	.067
Wood & bark	$\text{Log}_{10} Y = -2.86055 + 1.07295 \text{ Log}_{10} D^2Th$	.99	.034
ALL BRANCH MATERIAL[3]			
Wood	$\text{Log}_{10} Y = -5.22461 + 1.40575 \text{ Log}_{10} D^2Th$	.92	.156
Bark	$\text{Log}_{10} Y = -5.18476 + 1.31342 \text{ Log}_{10} D^2Th$	.94	.123
Wood & bark	$\text{Log}_{10} Y = -4.93996 + 1.37658 \text{ Log}_{10} D^2Th$	.93	.144

[1] $\text{Log}_{10} Y = b_0 + b_1 \text{ Log } D^2Th$

where: Y = cubic feet of tree or component,
D = d.b.h. in inches,
Th = total height in feet.

[2] Standard error of estimate in Log_{10} form.
[3] Regression equations based on 34 trees 6 to 20 inches d.b.h.
[4] Regression equations based on 26 trees 10 to 20 inches d.b.h.

YIELD TABLES

The equations in tables 9 and 10 were used to develop tables of biomass weight and volume. These tables of predicted yields are presented in the Appendix. Predicted green and dry weights of wood, bark, and needles in the total tree, main stem, and crown are presented in tables 11 through 21 by d.b.h. and total height classes. Predicted green cubic foot volume of wood and bark in the total tree, main stem, and branches are presented in tables 22 through 24.

Trees with the same d.b.h. and total height can vary considerably in weight and volume because of differences in crown size, moisture content, specific gravity, and taper. The yield tables presented in the Appendix should not be used indiscriminately over the range of shortleaf pine. Rather, they should be applied only to natural, closed stands of trees which are similar in age, taper rate, and wood properties to the trees sampled.

APPENDIX

Table 11.--Predicted weight of total tree (wood, bark, and needles) for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
	GREEN[3/]						
6	212	272	333	396			
7	299	384	471	559	650		
8	403	518	635	754	876	999	
9	525	674	826	982	1,140	1,301	1,464
10	664	853	1,046	1,243	1,443	1,647	1,853
11	822	1,056	1,295	1,539	1,787	2,038	2,294
12	999	1,283	1,573	1,870	2,171	2,477	2,787
13	1,195	1,535	1,882	2,236	2,597	2,963	3,334
14	1,411	1,811	2,222	2,640	3,066	3,498	3,935
15		2,114	2,593	3,081	3,578	4,082	4,593
16		2,443	2,996	3,560	4,134	4,716	5,306
17			3,431	4,077	4,734	5,402	6,078
18			3,899	4,634	5,381	6,139	6,907
19				5,230	6,073	6,929	7,796
20				5,866	6,812	7,772	8,745
	DRY[4/]						
6	103	132	162	192			
7	145	186	228	271	315		
8	195	251	308	365	424	484	
9	254	326	400	476	552	630	709
10	322	413	507	602	699	798	897
11	398	511	627	745	865	987	1,111
12	484	621	762	905	1,051	1,199	1,350
13	579	743	911	1,083	1,258	1,435	1,614
14	684	877	1,076	1,278	1,484	1,694	1,905
15		1,024	1,256	1,492	1,732	1,976	2,224
16		1,183	1,451	1,724	2,001	2,283	2,569
17			1,661	1,974	2,292	2,615	2,942
18			1,888	2,243	2,605	2,972	3,344
19				2,532	2,940	3,354	3,774
20				2,840	3,298	3,762	4,233

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -1.20938 + 1.11931 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -1.52244 + 1.11886 \text{ Log}_{10} D^2Th.$

Table 12.--Predicted weight of all aboveground wood excluding bark for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
	GREEN[3/]						
6	171	221	272	324			
7	244	314	387	461	537		
8	330	426	525	626	729	834	
9	432	558	687	819	954	1,091	1,230
10	550	709	873	1,041	1,213	1,387	1,565
11	683	882	1,086	1,295	1,508	1,725	1,945
12	834	1,075	1,324	1,579	1,839	2,104	2,372
13	1,001	1,291	1,590	1,896	2,208	2,525	2,848
14	1,185	1,529	1,883	2,245	2,615	2,991	3,373
15		1,790	2,204	2,628	3,061	3,501	3,949
16		2,074	2,554	3,045	3,547	4,057	4,575
17			2,933	3,497	4,073	4,659	5,255
18			3,342	3,985	4,641	5,309	5,987
19				4,508	5,250	6,006	6,773
20				5,068	5,903	6,752	7,615
	DRY[4/]						
6	82	106	130	155			
7	117	151	185	221	257		
8	158	204	251	300	349	399	
9	207	267	329	392	457	522	589
10	263	340	418	499	581	664	749
11	327	422	520	620	722	826	931
12	399	515	634	756	880	1,007	1,136
13	479	618	761	907	1,057	1,209	1,363
14	568	732	901	1,075	1,251	1,431	1,614
15		857	1,055	1,258	1,465	1,675	1,889
16		993	1,222	1,457	1,697	1,941	2,189
17			1,404	1,673	1,949	2,229	2,514
18			1,599	1,907	2,220	2,539	2,864
19				2,157	2,512	2,873	3,240
20				2,425	2,823	3,230	3,642

1/ Blocked-in area indicates range of data.
2/ Includes 1-foot stump allowance.
3/ $\text{Log}_{10} Y = -1.37140 + 1.14146 \text{ Log}_{10} D^2Th.$
4/ $\text{Log}_{10} Y = -1.68837 + 1.14073 \text{ Log}_{10} D^2Th.$

Table 13.--Predicted weight of all aboveground bark for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
	GREEN[3/]						
6	28	35	42	50			
7	39	48	58	68	77		
8	50	63	76	89	101	114	
9	64	80	96	112	128	145	161
10	79	99	119	139	159	179	199
11	96	120	144	168	192	217	241
12	114	143	172	200	229	258	287
13	134	168	202	235	269	303	337
14	156	195	234	273	313	352	391
15		224	269	314	359	404	450
16		255	306	358	409	460	512
17			346	404	462	520	578
18			388	453	518	584	649
19				505	578	651	724
20				560	641	722	802
	DRY[4/]						
6	16	20	24	28			
7	22	27	32	38	43		
8	28	35	42	50	57	64	
9	36	45	54	63	72	81	90
10	44	55	67	78	89	100	112
11	54	67	81	94	108	122	135
12	64	80	96	113	129	145	161
13	75	94	113	132	151	170	190
14	87	109	131	154	176	198	220
15		126	151	177	202	228	253
16		143	172	201	230	259	288
17			195	227	260	293	326
18			218	255	292	329	366
19				285	326	367	408
20				316	361	407	453

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -1.72900 + 1.00681 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -1.99159 + 1.00983 \text{ Log}_{10} D^2Th.$

Table 14.--Predicted weight of needles for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
	GREEN[3/]						
6	12	15	18	21			
7	16	21	25	29	33		
8	22	27	33	38	43	49	
9	27	34	41	48	55	62	69
10	34	42	51	60	68	77	86
11	41	51	62	72	83	93	104
12	49	61	74	86	99	111	124
13	58	72	87	101	116	131	145
14	67	84	101	118	135	152	169
15		96	116	135	155	175	194
16		110	132	154	177	199	221
17			149	174	200	225	250
18			168	196	224	252	281
19				218	250	282	313
20				242	277	312	347
	DRY[4/]						
6	5	6	7	8			
7	6	8	10	11	13		
8	8	11	13	15	17	19	
9	11	13	16	19	22	25	28
10	13	17	20	24	27	31	34
11	16	20	25	29	33	38	42
12	19	24	29	35	40	45	50
13	23	29	35	41	47	53	59
14	27	34	41	48	55	62	69
15		39	47	55	63	71	80
16		44	54	63	72	82	91
17			61	71	82	93	103
18			68	80	92	104	116
19				90	103	117	130
20				100	115	130	145

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -2.11075 + 1.01076 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -2.61282 + 1.03712 \text{ Log}_{10} D^2Th.$

Table 15.--Predicted weight of wood and bark in main stem to 2-inch d.i.b. top for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
	GREEN[3/]						
6	187	239	291	344			
7	262	334	407	481	556		
8	350	446	544	644	744	846	
9	452	577	703	832	962	1,093	1,226
10	569	725	884	1,046	1,210	1,375	1,542
11	700	892	1,088	1,287	1,489	1,692	1,898
12	846	1,079	1,315	1,556	1,799	2,045	2,294
13	1,007	1,284	1,566	1,852	2,142	2,434	2,730
14	1,183	1,509	1,840	2,176	2,516	2,861	3,208
15		1,753	2,138	2,529	2,924	3,324	3,728
16		2,018	2,461	2,910	3,365	3,826	4,291
17			2,808	3,321	3,840	4,366	4,896
18			3,180	3,761	4,349	4,944	5,545
19				4,231	4,892	5,562	6,238
20				4,730	5,470	6,219	6,974
	DRY[4/]						
6	93	118	144	170			
7	130	165	201	238	275		
8	173	220	268	317	367	417	
9	223	284	347	410	473	538	603
10	281	357	435	515	595	676	757
11	345	439	535	633	731	831	931
12	417	531	646	764	883	1,003	1,124
13	495	631	769	909	1,050	1,193	1,337
14	582	741	903	1,067	1,233	1,401	1,570
15		860	1,048	1,239	1,432	1,627	1,824
16		990	1,206	1,425	1,647	1,871	2,098
17			1,375	1,625	1,878	2,134	2,392
18			1,557	1,840	2,126	2,415	2,708
19				2,068	2,390	2,716	3,044
20				2,311	2,671	3,035	3,402

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -1.16592 + 1.08852 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -1.45537 + 1.08367 \text{ Log}_{10} D^2Th.$

Table 16.--Predicted weight of wood excluding bark in main stem to 2-inch d.i.b. top for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
GREEN[3/]							
6	163	208	255	303			
7	229	293	359	426	494		
8	308	394	483	573	664	757	
9	400	512	627	744	863	983	1,105
10	505	647	792	940	1,090	1,242	1,396
11	624	799	979	1,161	1,347	1,534	1,725
12	757	970	1,187	1,408	1,633	1,861	2,092
13	904	1,158	1,418	1,682	1,951	2,223	2,499
14	1,066	1,365	1,671	1,983	2,299	2,620	2,945
15		1,591	1,947	2,311	2,680	3,054	3,432
16		1,836	2,247	2,666	3,092	3,524	3,961
17			2,571	3,050	3,537	4,031	4,531
18			2,918	3,463	4,016	4,576	5,143
19				3,904	4,527	5,159	5,799
20				4,375	5,073	5,781	6,498
DRY[4/]							
6	79	101	123	146			
7	111	142	173	206	238		
8	149	191	233	276	320	365	
9	193	247	302	359	416	474	532
10	244	312	382	453	525	598	672
11	301	385	471	559	648	738	829
12	365	467	571	678	785	895	1,005
13	436	558	682	809	938	1,068	1,200
14	513	657	804	953	1,105	1,258	1,414
15		765	936	1,110	1,287	1,466	1,647
16		883	1,080	1,280	1,484	1,691	1,899
17			1,235	1,464	1,697	1,933	2,172
18			1,401	1,661	1,926	2,194	2,465
19				1,872	2,170	2,472	2,778
20				2,097	2,431	2,769	3,111

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -1.29252 + 1.10935 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -1.59597 + 1.10579 \text{ Log}_{10} D^2Th.$

Table 17.--Predicted weight of bark in main stem to 2-inch d.i.b. top for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
	GREEN[3/]						
6	25	30	36	41			
7	33	40	47	54	61		
8	42	51	60	69	78	87	
9	52	63	75	86	97	108	118
10	63	77	90	104	117	130	143
11	74	91	107	123	139	154	170
12	87	106	125	144	163	181	199
13	100	123	145	166	188	209	230
14	115	140	166	190	215	239	263
15		159	188	216	243	270	297
16		179	211	242	273	304	334
17			235	270	305	339	373
18			261	300	338	376	413
19				330	373	414	456
20				362	409	455	500
	DRY[4/]						
6	14	17	20	24			
7	19	23	27	31	35		
8	24	29	35	40	45	50	
9	30	36	43	50	56	63	69
10	36	44	52	60	68	76	84
11	43	53	62	72	81	91	100
12	50	62	73	84	95	106	117
13	58	72	85	98	111	123	136
14	67	82	97	112	127	141	156
15		93	110	127	144	160	177
16		105	124	143	162	181	199
17			139	160	181	202	222
18			154	178	201	224	247
19				197	222	248	273
20				216	244	272	300

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -1.45510 + 0.90264 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -1.75626 + 0.91986 \text{ Log}_{10} D^2Th.$

Table 18.--Predicted weight of crown material (branchwood, branchbark, and needles) in shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
	GREEN[3/]						
6	26	34	43	52			
7	38	50	63	77	91		
8	53	70	89	108	128	148	
9	71	95	120	145	172	200	228
10	93	124	156	190	225	261	298
11	119	158	199	242	286	332	380
12	148	197	248	301	357	414	474
13	182	241	304	369	437	508	580
14	219	291	366	446	528	613	700
15		346	436	531	629	730	834
16		408	514	625	740	860	982
17			600	729	863	1,002	1,146
18			693	843	998	1,159	1,324
19				966	1,145	1,329	1,519
20				1,101	1,304	1,514	1,730
	DRY[4/]						
6	11	14	18	22			
7	16	21	27	33	39		
8	22	30	38	47	55	65	
9	31	41	52	63	75	88	101
10	40	54	68	83	99	116	133
11	52	69	87	107	127	148	170
12	65	86	110	134	159	186	213
13	80	107	135	165	196	229	263
14	97	129	164	200	238	278	319
15		155	196	240	285	333	382
16		183	232	284	338	394	451
17			272	332	395	461	529
18			315	386	459	535	614
19				444	528	616	706
20				507	604	704	807

1/ Blocked-in area indicates range of data.
2/ Includes 1-foot stump allowance.
3/ $\text{Log}_{10} Y = -2.59672 + 1.26786 \text{ Log}_{10} D^2Th.$
4/ $\text{Log}_{10} Y = -3.08921 + 1.30297 \text{ Log}_{10} D^2Th.$

Table 19.--Predicted weight of wood and bark in branches for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
	GREEN[3/]						
6	14	20	25	31			
7	22	30	39	48	57		
8	32	43	56	69	83	97	
9	44	60	77	95	115	135	156
10	59	80	103	127	153	180	208
11	77	104	134	166	199	234	270
12	97	132	170	210	253	297	343
13	121	165	212	262	315	370	428
14	149	202	260	321	386	454	525
15		245	314	388	467	549	634
16		292	375	464	557	655	758
17			443	548	659	774	895
18			519	641	771	906	1,048
19				744	894	1,052	1,215
20				857	1,030	1,211	1,400
	DRY[4/]						
6	6	9	11	14			
7	10	13	17	22	26		
8	14	20	25	31	38	45	
9	20	27	35	44	52	62	72
10	27	37	47	58	70	83	96
11	35	48	62	76	92	109	126
12	45	61	78	97	117	138	160
13	56	76	98	122	147	173	201
14	69	94	121	150	181	213	247
15		114	147	182	219	259	300
16		136	176	218	263	310	359
17			208	258	311	367	425
18			244	303	365	431	499
19				353	425	501	581
20				407	491	578	670

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -3.18256 + 1.37516 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -3.61440 + 1.39952 \text{ Log}_{10} D^2Th.$

Table 20.--Predicted weight of branchwood in shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
GREEN[3/]							
6	10	14	18	22			
7	16	22	28	35	42		
8	23	31	41	50	61	72	
9	32	44	56	70	85	100	116
10	43	59	76	94	114	134	155
11	56	77	99	123	148	175	203
12	72	98	127	157	190	224	259
13	90	123	158	197	237	280	325
14	110	151	195	242	292	345	400
15		183	237	294	355	419	485
16		220	284	353	425	502	582
17			337	418	504	595	690
18			395	491	592	699	810
19				571	689	813	943
20				660	796	939	1,089
DRY[4/]							
6	4	6	8	10			
7	7	9	12	15	18		
8	10	14	18	22	27	32	
9	14	19	25	31	38	44	52
10	19	26	34	42	51	60	70
11	25	34	44	55	67	79	92
12	32	44	57	71	86	102	119
13	40	55	72	89	108	128	149
14	49	68	89	111	134	159	185
15		83	108	135	164	194	226
16		100	130	163	197	233	272
17			155	194	235	278	324
18			183	228	277	328	382
19				267	323	383	446
20				309	375	444	517

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -3.42558 + 1.40428 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -3.91892 + 1.44117 \text{ Log}_{10} D^2Th.$

Table 21.--Predicted weight of branchbark in shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Pounds						
GREEN[3/]							
6	4	6	7	9			
7	6	9	11	13	16		
8	9	12	15	18	22	26	
9	12	16	21	25	30	35	40
10	16	21	27	33	39	45	52
11	20	27	34	42	50	58	66
12	26	34	43	53	62	73	83
13	31	42	53	65	77	89	102
14	38	51	64	78	93	108	124
15		60	76	93	111	129	148
16		71	90	110	131	152	174
17			106	129	153	178	204
18			122	149	177	206	236
19				171	203	237	271
20				196	232	270	309
DRY[4/]							
6	2	3	4	4			
7	3	4	5	7	8		
8	4	6	8	9	11	13	
9	6	8	10	12	15	17	20
10	8	11	13	16	19	23	26
11	10	14	17	21	25	29	33
12	13	17	21	26	31	36	41
13	16	21	26	32	38	44	51
14	19	25	32	39	46	54	62
15		30	38	46	55	64	74
16		36	45	55	65	76	87
17			53	64	76	89	102
18			61	74	88	103	118
19				86	102	118	135
20				98	116	135	155

1/ Blocked-in area indicates range of data.
2/ Includes 1-foot stump allowance.
3/ $\text{Log}_{10} Y = -3.43184 + 1.28689 \text{ Log}_{10} D^2Th.$
4/ $\text{Log}_{10} Y = -3.74810 + 1.29018 \text{ Log}_{10} D^2Th.$

able 22.--Predicted green volume of wood and bark in a total tree for shortleaf pine trees 6 to 20 inches d.b.h.

.b.h. inches)	Total tree height (feet)[2]						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD[3]						
6	2.8	3.6	4.4	5.3			
7	3.9	5.1	6.3	7.5	8.7		
8	5.4	6.9	8.5	10.2	11.8	13.6	
9	7.0	9.1	11.2	13.3	15.5	17.8	20.0
10	8.9	11.5	14.2	17.0	19.8	22.6	25.5
11	11.1	14.3	17.7	21.1	24.6	28.1	31.7
12	13.6	17.5	21.6	25.7	30.0	34.3	38.7
13	16.3	21.0	25.9	30.9	36.0	41.2	46.5
14	19.3	24.9	30.7	36.6	42.7	48.9	55.1
15		29.2	36.0	42.9	50.0	57.2	64.6
16		33.8	41.7	49.7	58.0	66.3	74.8
17			47.9	57.2	66.6	76.2	86.0
18			54.6	65.2	75.9	86.9	98.0
19				73.7	85.9	98.3	110.9
20				82.9	96.6	110.6	124.8
	BARK[4]						
6	0.8	1.0	1.2	1.4			
7	1.1	1.4	1.6	1.9	2.2		
8	1.4	1.8	2.1	2.5	2.8	3.1	
9	1.8	2.2	2.7	3.1	3.5	3.9	4.4
10	2.2	2.7	3.3	3.8	4.3	4.8	5.3
11	2.6	3.3	3.9	4.6	5.2	5.8	6.4
12	3.1	3.9	4.6	5.4	6.1	6.9	7.6
13	3.7	4.5	5.4	6.3	7.2	8.0	8.9
14	4.2	5.2	6.3	7.3	8.3	9.3	10.3
15		6.0	7.2	8.3	9.5	10.6	11.7
16		6.8	8.1	9.4	10.7	12.0	13.3
17			9.1	10.6	12.0	13.5	14.9
18			10.2	11.8	13.5	15.1	16.7
19				13.1	14.9	16.7	18.5
20				14.5	16.5	18.5	20.5

continued

Table 22.--Predicted green volume of wood and bark in a total tree for shortleaf pine trees 6 to 20 inches d.b.h.[1/] (continued)

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD AND BARK[5/]						
6	3.6	4.6	5.6	6.7			
7	5.1	6.5	7.9	9.4	10.9		
8	6.8	8.7	10.7	12.7	14.7	16.8	
9	8.8	11.3	13.9	16.5	19.1	21.8	24.5
10	11.2	14.3	17.5	20.8	24.2	27.5	31.0
11	13.8	17.7	21.7	25.7	29.9	34.0	38.3
12	16.8	21.5	26.3	31.2	36.2	41.3	46.4
13	20.0	25.7	31.4	37.3	43.3	49.4	55.5
14	23.6	30.3	37.1	44.0	51.1	58.2	65.4
15		35.3	43.2	51.3	59.5	67.9	76.3
16		40.7	49.9	59.2	68.7	78.3	88.1
17			57.1	67.8	78.6	89.6	100.8
18			64.9	77.0	89.3	101.8	114.4
19				86.8	100.7	114.8	129.1
20				97.3	112.9	128.7	144.7

1/ Blocked-in area indicates range of data.
2/ Includes 1-foot stump allowance.
3/ $\text{Log}_{10} Y = -3.17412 + 1.14519 \text{ Log}_{10} D^2Th.$
4/ $\text{Log}_{10} Y = -3.14403 + 0.96809 \text{ Log}_{10} D^2Th.$
5/ $\text{Log}_{10} Y = -2.95720 + 1.11202 \text{ Log}_{10} D^2Th.$

Table 23.--Predicted green volume of wood and bark in main stem to 2-inch d.i.b. top for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

d.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD[3/]						
6	2.6	3.4	4.1	4.9			
7	3.7	4.8	5.8	6.9	8.0		
8	5.0	6.4	7.8	9.3	10.8	12.3	
9	6.5	8.3	10.2	12.1	14.1	16.0	18.0
10	8.2	10.5	12.9	15.3	17.8	20.3	22.8
11	10.2	13.0	16.0	18.9	22.0	25.1	28.2
12	12.3	15.8	19.4	23.0	26.7	30.4	34.2
13	14.7	18.9	23.1	27.5	31.9	36.4	40.9
14	17.4	22.3	27.3	32.4	37.6	42.9	48.2
15		26.0	31.8	37.8	43.9	50.0	56.2
16		30.0	36.8	43.6	50.6	57.7	64.9
17			42.1	49.9	58.0	66.1	74.3
18			47.8	56.7	65.8	75.0	84.4
19				64.0	74.2	84.6	95.2
20				71.7	83.2	94.9	106.7
	BARK[4/]						
6	0.8	0.9	1.1	1.2			
7	1.0	1.2	1.4	1.6	1.8		
8	1.2	1.5	1.8	2.0	2.3	2.5	
9	1.5	1.9	2.2	2.5	2.8	3.1	3.4
10	1.8	2.2	2.6	3.0	3.3	3.7	4.1
11	2.2	2.6	3.1	3.5	4.0	4.4	4.8
12	2.5	3.1	3.6	4.1	4.6	5.1	5.6
13	2.9	3.5	4.1	4.7	5.3	5.8	6.4
14	3.3	4.0	4.7	5.3	6.0	6.7	7.3
15		4.5	5.3	6.0	6.8	7.5	8.2
16		5.0	5.9	6.7	7.6	8.4	9.2
17			6.6	7.5	8.4	9.3	10.2
18			7.2	8.3	9.3	10.3	11.3
19				9.1	10.2	11.3	12.4
20				9.9	11.2	12.4	13.5

continued

Table 23.--Predicted green volume of wood and bark in main stem to 2-inc d.i.b. top for shortleaf pine trees 6 to 20 inches d.b.h.[1/] (continuec

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD AND BARK[5/]						
6	3.4	4.3	5.2	6.2			
7	4.7	6.0	7.3	8.6	9.9		
8	6.3	7.9	9.7	11.4	13.2	14.9	
9	8.1	10.2	12.4	14.7	16.9	19.2	21.5
10	10.1	12.8	15.6	18.4	21.2	24.1	27.0
11	12.4	15.7	19.1	22.6	26.1	29.6	33.1
12	14.9	19.0	23.1	27.2	31.4	35.7	39.9
13	17.7	22.5	27.4	32.3	37.3	42.3	47.4
14	20.8	26.4	32.1	37.9	43.7	49.6	55.6
15		30.6	37.2	43.9	50.7	57.5	64.4
16		35.2	42.8	50.5	58.2	66.1	74.0
17			48.7	57.5	66.3	75.3	84.3
18			55.1	65.0	75.0	85.1	95.3
19				73.0	84.2	95.6	107.0
20				81.5	94.0	106.7	119.5

1/ Blocked-in area indicates range of data.
2/ Includes 1-foot stump allowance.
3/ $\text{Log}_{10} Y = -3.09675 + 1.11362 \text{ Log}_{10} D^2Th.$
4/ $\text{Log}_{10} Y = -2.86454 + 0.86838 \text{ Log}_{10} D^2Th.$
5/ $\text{Log}_{10} Y = -2.86055 + 1.07295 \text{ Log}_{10} D^2Th.$

Table 24.--Predicted green volume of wood and bark in branches for shortleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD [3/]						
6	0.2	0.2	0.3	0.4			
7	.3	.3	.4	.6	0.7		
8	.4	.5	.7	.8	1.0	1.2	
9	.5	.7	.9	1.1	1.4	1.6	1.9
10	.7	.9	1.2	1.5	1.8	2.2	2.5
11	.9	1.2	1.6	2.0	2.4	2.8	3.3
12	1.2	1.6	2.0	2.5	3.1	3.6	4.2
13	1.4	2.0	2.6	3.2	3.8	4.5	5.2
14	1.8	2.4	3.1	3.9	4.7	5.6	6.4
15		3.0	3.8	4.7	5.7	6.7	7.8
16		3.5	4.6	5.7	6.9	8.1	9.4
17			5.4	6.7	8.1	9.6	11.1
18			6.4	7.9	9.5	11.3	13.1
19				9.2	11.1	13.1	15.2
20				10.6	12.8	15.1	17.6
	BARK [4/]						
6	0.1	0.1	0.2	0.2			
7	.1	.2	.2	.3	0.3		
8	.2	.3	.3	.4	.5	0.6	
9	.3	.4	.5	.6	.7	.8	0.9
10	.4	.5	.6	.7	.9	1.0	1.2
11	.5	.6	.8	.9	1.1	1.3	1.5
12	.6	.8	1.0	1.2	1.4	1.6	1.9
13	.7	.9	1.2	1.5	1.7	2.0	2.3
14	.9	1.1	1.5	1.8	2.1	2.5	2.8
15		1.4	1.7	2.1	2.5	3.0	3.4
16		1.6	2.1	2.5	3.0	3.5	4.0
17			2.4	3.0	3.5	4.1	4.7
18			2.8	3.4	4.1	4.8	5.5
19				4.0	4.7	5.5	6.3
20				4.5	5.4	6.3	7.2

continued

Table 24.--Predicted green volume of wood and bark in branches for shortlea

pine trees 6 to 20 inches d.b.h.[1/] (continued)

D.b.h. (inches)	Total tree height (feet)[2/]						
	40	50	60	70	80	90	100
	Cubic feet						
	WOOD AND BARK[5/]						
6	0.3	0.3	0.4	0.6			
7	.4	.5	.7	.8	1.0		
8	.6	.8	1.0	1.2	1.5	1.7	
9	.8	1.1	1.4	1.7	2.0	2.4	2.8
10	1.0	1.4	1.8	2.3	2.7	3.2	3.7
11	1.4	1.8	2.4	2.9	3.5	4.1	4.8
12	1.7	2.3	3.0	3.7	4.5	5.3	6.1
13	2.1	2.9	3.8	4.6	5.6	6.6	7.6
14	2.6	3.6	4.6	5.7	6.8	8.0	9.3
15		4.3	5.6	6.9	8.3	9.7	11.3
16		5.2	6.7	8.2	9.9	11.6	13.4
17			7.9	9.7	11.7	13.7	15.9
18			9.2	11.4	13.7	16.1	18.6
19				13.2	15.9	18.7	21.6
20				15.2	18.3	21.5	24.8

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -5.22461 + 1.40575 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -5.18476 + 1.31342 \text{ Log}_{10} D^2Th.$
[5/] $\text{Log}_{10} Y = -4.93996 + 1.37658 \text{ Log}_{10} D^2Th.$

Clark, Alexander III, and Michael A. Taras
1976. Biomass of shortleaf pine in a natural sawtimber stand in northern Mississippi. USDA For. Serv. Res. Pap. SE-146. 32 p. Southeast. For. Exp. Stn., Asheville, N.C.

Shortleaf pine trees 6 to 20 inches d.b.h. were selected from a natural, uneven-aged sawtimber stand in northern Mississippi to determine weight and volume of aboveground biomass. On the average, 84 percent of the dry weight of the total tree was wood, 12 percent was bark, and 4 percent was needles. The average tree sampled had 88 percent of its wood in the stem and 12 percent in the crown. Trends in biomass proportions are discussed; and specific gravity, moisture content, and green weight per cubic foot are presented for the total tree and its components. Tables developed with regression equations predict weight and volume of the total tree and its components by d.b.h. and total height classes.

Keywords: Pinus echinata Mill., weight, volume, prediction equations, component proportions.

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Forest Service Research Paper SE-147 June 1976

Management of Natural Stands of Slash Pine

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U.S. Department of Agriculture-Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Management of Natural Stands of Slash Pine[1]

by

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Abstract.--Information is presented on reproducing slash pine stands by the seed tree and shelterwood methods. Precommercial thinning is recommended for dense young stands. Under good management, natural stands yield as much as plantations.

Keywords: Pinus elliottii, precommercial thinning, growth, yield, natural reproduction.

Slash pine has come a long way! In virgin forests of the South, pure stands of slash pine were uncommon except in the lower peninsula and Gulf Coast of Florida (Forbes 1930). Elsewhere, it was confined largely to wet sites such as the borders of small streams and ponds. Wildfire played an important role in its distribution because slash pine seedlings usually cannot survive a burn. In the early portion of the century, and especially after World War I, slash pine seeded onto many abandoned fields in the agricultural areas of its range. And in the early to midthirties after fire protection was first imposed, slash pine began to invade longleaf pine lands. When we couple this with the extensive plantings of slash, we have the picture of slash pine replacing longleaf pine on many acres (McCulley 1950). Slash pine now occupies about 12.2 million acres of which some 6.7 million acres originated from natural regeneration.

Sufficient information is available on the silvical characteristics of slash pine to recommend systems for natural regeneration, and research has indicated probable responses of stands to specific silvicultural practices. In this paper we recommend even-aged management of slash pine, strongly recommend precommercial thinning of dense stands, and discuss probable responses to commercial thinnings. The information is applicable to the more than 6 million acres of natural stands and to any plantations that managers may reproduce through natural seeding.

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[1]Based on talk presented January 31, 1974, at the 1974 annual meeting, Southeastern Section, Society of American Foresters, Mobile, Alabama.

[2]Retired.

SILVICAL CHARACTERISTICS

Slash pine produces relatively large cone and seed crops at about 3-year intervals (Cooper and Perry 1956). Crown release, stem injury, or fertilization imposed 3 years in advance of the desired crop can increase seed production by from 50 to 200 percent. Most seeds are dispersed between late September and November, and germination takes place over the period from November through April (Cooper 1965).

Slash pine often invades abandoned fields and becomes established when fire is exclu

Although burning or disking a seedbed will usually increase seedl catches several-fold (Osborne and Harper 1937), such seedbed preparation for stand establishment is normally only necessary if a poor seed crop i anticipated. Benefits from site preparation may be more important for h ard reduction and for facilitating later cultural operations than for st establishment. For example, a young slash pine stand, 12 to 15 feet tal can be prescribed burned if the site was prepared prior to regeneration cause the understory will be only 1 to 2 feet high and composed primaril of native grasses and herbs. However, in a similar stand not site-prepa the sawpalmetto or gallberry may be head high. Prescribed burning in su stands should not be considered until the trees are much larger because fire damage. Also, the risk of complete loss of slash pine from a wildf is greater in stands not site-prepared.

Slash pine has traditionally been considered intermediate in tole ance (Cooper 1965) mainly because it will reproduce in small openings an has invaded poorly stocked longleaf pine stands. But competition from overstory and from understory vegetation greatly reduces growth and resu

in high mortality. In our opinion, slash pine should be classified as intolerant. Results from an interplanting study on the Holt Walton Experimental Forest in Georgia support this conclusion. A plantation spaced 15' by 15' feet was converted to a 7½ by 15' spacing by interplanting in one direction 1 year after the original planting. The 1-year age difference reduced height growth of the interplants after 8 years by 70 percent (Bennett 1954). At age 25' the yield from trees originally planted was 28.9 cords while the interplants contained only 2.6 cords per acre.

Interplanting failures demonstrate slash pine's intolerance. Trees in center row were planted only 1 year later than the others.

Slash pine has two principal diseases: fusiform rust and annosus root rot. Fusiform rust is more serious because it reduces growth, kills and deforms many trees and because no practical control measures are known. Incidence of annosus root rot is usually greater following cuttings in late fall and winter than in late spring and summer (Ross 1970). Stumps from thinnings are usually the source of infection. Thinning only in the warm season and, in some cases, not thinning at all appear to be measures for limiting annosus infection. Application of chemical retardants (e.g., borax) or fungal competitors to cut stumps also helps to prevent root rot (Hodges 1969; Koenigs 1971).

SILVICULTURAL SYSTEMS

Since slash pine is either intolerant or nearly so, we do not recommend all-aged management for the species. Overtopping, which is unavoidable in all-aged management, would reduce growth and yield. With many ages and sizes of trees growing in a relatively small area, area-wide treatments, particularly prescribed burning for hazard reduction and wildlife habitat improvement, would be impossible. Hence, all-aged slash pine forests would have a continuous fire problem. Site preparation and hardwood control also are impractical unless done in contiguous and well-defined areas. Finally, in all-aged stands harvesting would be more frequent, and the incidence of annosus root rot therefore would probably be greater.

If a landowner insists on all-aged management for reasons that overrule the limitations enumerated above, then the group-selection method of harvest cutting should be applied. Under this method mature trees are harvested in small groups of an acre or so in size, and reproduction is obtained in small even-aged groups.

Under even-aged management both the seed-tree and shelterwood systems are satisfactory. Leave 6 to 10 seed trees per acre or 25 to 40 shelterwood trees per acre when the main portion of the stand is harvested (Langdon and Schultz 1973). In either case, the seedbed should be matched with the seed crop. If a poor seed year is predicted, prescribe burn or mechanically prepare the seedbed. If a heavy understory of sawpalmetto or hardwoods is present, it is usually desirable to control this vegetation. This work should be done prior to the regeneration or harvest cut. The seed or shelterwood trees should be removed 1 to 3 years after the regeneration cut. A frequent mistake is the failure to harvest the seed trees promptly after seedlings are established.

Slash pine seeds readily both beneath trees and in openings, but the overstory must be removed promptly to get satisfactory seedling growth.

PRECOMMERCIAL THINNING

A precommercial thinning study near Cordele, Georgia (Collins 1967) showed that high stand density decreased height growth of young dominant and codominant slash pine and merchantable volume growth. Differences in height in favor of the low density were as much as 15 feet at age 17 between the extreme densities. Merchantable cordwood-volume differences were sizable--some 15 cords or nearly 90 percent less growth on the unthinned plots than on the thinned (table 1).

The results of this study have broad management implications. If dense stands of slash pine are not thinned a few years after establishment, site potential (as estimated by dominant tree height) will be greatly underestimated. More importantly, growth in height, diameter, and merchantable volume will be severely reduced, and the full growth potential of site will not be realized.

Table 1.--Results at age 17 of precommercial thinning slash pine at age 3 (after Collins 1967)

Thinning treatment	Surviving trees/acre	Mean dominant tree		Volume per acre
		Height	Diameter	
		Feet	Inches	Cords
Control (unthinned)	5,762	31.8	2.4	1.5
Clump (10 x 10)	1,450	38.4	3.8	9.9
Single tree (10 x 10)	366	42.4	6.6	16.8

In our opinion, early control of stocking may be more important for natural slash pine stands than selecting the correct spacing for a plantation. We recommend that stands with more than 1,000 stems per acre be precommercially thinned, especially if sawtimber, plywood or gum are primary product objectives. This means that the landowner in consultation with his forester should set forth his product objectives early in the life of the stand. A study by McMinn (1965) illustrates our point. The study was established in north Florida in 1935 when a naturally regenerated slash pine stand was 7 years old and stocking was about 3,500 trees per acre. Three levels of precommercial thinning plus an unthinned check plot were imposed. The precommercial thinning regimes and residual numbers of trees were: light (700 trees/acre), moderate (400 trees/acre), heavy (200 trees/acre), and unthinned check (3,500 trees/acre).

Merchantable cubic-foot production was consistently highest on the lightly thinned plots from age 17 to 35 (table 2). At age 35 this stocking level produced about 6,500 cubic feet as compared to 5,400 cubic feet for the check plots and about 5,100 and 3,800 cubic feet for moderately and heavily thinned plots, respectively. Some merchantable pulpwood growth was lost by moderate and heavy thinnings, as well as by not thinning at all.

As one might expect, diameter of the 100 largest trees per acre was greatly influenced by degree of thinning (table 2). The heavily thinned plots had the largest trees and the unthinned checks the smallest. As a result, sawtimber yields at age 27 and 35 were greatest on heavily thinned plots. Heavy thinning resulted in nearly 13,000 board feet at age 35, while only 4,500 board feet were present at the same age on unthinned plots.

Table 2.--Tree size and product yields per acre of slash pine by precommercial thinning regimes (after McMinn 1965)

Thinning regime	Tree size or product[1]	Age (years)			
		18	22	27	35
		Average size or product yield/acre			
Heavy	Diameter (inches)	9.4	10.3	11.5	12.8
	Pulpwood (cubic feet)	1,500	1,900	3,100	3,850
	Sawtimber (board feet)	--	--	7,500	12,900
	Gum (pounds)	--	--	--	1,500
Moderate	Diameter (inches)	8.5	9.4	10.8	11.8
	Pulpwood (cubic feet)	2,050	2,450	3,950	5,100
	Sawtimber (board feet)	--	--	4,800	11,500
	Gum (pounds)	--	--	--	1,550
Light	Diameter (inches)	7.9	9.0	10.0	11.0
	Pulpwood (cubic feet)	2,850	3,700	5,400	6,500
	Sawtimber (board feet)	--	--	2,600	9,100
	Gum (pounds)	--	--	--	1,590
Check (unthinned)	Diameter (inches)	6.7	7.6	8.1	10.4
	Pulpwood (cubic feet)	1,700	2,700	4,200	5,400
	Sawtimber (board feet)	--	--	900	4,500
	Gum (pounds)	--	--	--	730

[1]Average diameter is for the 100 largest trees per acre. Pulpwood includes merchantable volume of standing timber and that removed in commercial thinnings. Sawtimber includes trees 10 inches and larger with volumes estimated by 1/4-inch International Rule. Gum yield is a 1-year estimate in a 4-year chipping cycle for 9-inch and larger trees.

Estimated gum yields per acre from trees 9 inches and larger are about equal for the three thinning treatments (table 2), but on the heavily thinned gum production would be from fewer trees which would decrease costs and result in greater net returns.

This case history shows the need for establishing product objectives at an early age. Heavy precommercial thinnings favor sawtimber and profitable gum production, whereas the light thinnings favor pulpwood or the combination of pulpwood and sawtimber products. In either case, it appears that increased returns would more than pay for precommercial thinning.

Many well-stocked natural stands of slash pine can be found. Judicious precommercial and commercial thinnings can make these stands highly productive.

COMMERCIAL THINNING

Commercial thinning, the cutting of merchantable-sized trees usually includes one or more of the following objectives: (1) to salvage dying, diseased, and poorly formed trees, (2) to increase the size (quality) of residual trees, and (3) to increase total yields. Bennett (1971) has discussed these objectives in relation to slash pine plantations. He concluded that when management is product-oriented, the product objective will dictate initial spacing and that thinnings in short- to medium-length rotations will play a secondary role--mostly as a sanitation and salvage measure and not as a growth regulator. For longer rotations with multiple product objectives, thinning will play a more conventional role in maintaining stand vigor and diameter growth. Bennett (1971) and others (Keister and others 1968; Wakeley 1969) have found that thinning at about age 15 in slash pine plantations has little, if any, effect on total cubic yields and thus the objective of increasing yields by thinning is largely unattainable. These

conclusions also appear applicable to natural slash pine. Bennett's (1970a) growth and yield results for managed natural slash pine allow one to simulate thinning under various basal area controls. Table 3 illustrates that cubic yields under several thinning regimes are similar.

Table 3.--Simulated yields at age 50 of natural slash pine by thinning regimes and basal area controls (adapted from Bennett 1970a)[1]

Site index	Number thinnings	Basal area control (square feet)		
		75	100	125
		- - - - - Cubic feet - - - - -		
80	0	--	--	5,339
80	1	5,350	5,375	5,388
80	2	5,347	5,416	5,410
80	3	5,344	5,431	--
100	0	--	--	7,238
100	1	7,253	7,286	7,306
100	2	7,249	7,340	7,336
100	3	7,243	7,362	--

[1]Yields include volume removed in thinnings. All comparisons for a site had equal volume at age 20. First thinning was made at age 20 to basal area control; second thinning was made at age 30 to basal area control; third thinning made at age 40 to basal area control.

In stands not precommercially thinned, the timing of the first commercial thinning depends heavily on initial stocking because stocking greatly influences the time required for a stand to reach merchantable size. If initial stocking is excessive, a commercial thinning may not be silviculturally desirable until the stand is about 30 years old. Before that time, a merchantable thinning would take the large trees and leave the small ones and thus be an undesirable high-grading practice. The growth response for the residuals would be less at age 30 than at younger ages, for slash pines that are old grown in dense stands have very low crown ratios (Bennett 1960). Such trees respond slowly to thinning because slow height growth at that age limits the increase in crown length, which, in turn, affects volume growth. From the standpoint of total merchantable cubic-volume production during the subsequent 25 to 30 years, clearcutting and regenerating at an acceptable density level would be the preferred course for these stands. For example, in stands of acceptable density, mean annual merchantable cubic-volume increment culminates by age 30 or shortly thereafter.

YIELDS COMPARISONS OF PLANTED AND NATURAL STANDS

Most foresters contend that planted slash pine (without genetically improved stock) will outproduce natural stands. This concession is valid if the natural stands are not managed--if density has not been controlled in the early life of the stand through precommercial thinning. But is this a fair comparison? In the Cordele precommercial thinning study (table 1), the yield at age 17 of the single-tree thinned plots is about 15 cords more than on unthinned plots. The yield of those thinned plots compares very favorably with plantation yields of the same spacing and site (Bennett 1970b). Such a plantation would yield 16.4 cords at the same age--practically the same as this natural stand.

The above illustrates the point that if a plantation of unimproved stock and a natural stand have equivalent site indices and stand density history, their yields should be essentially the same. Otherwise, the validity of site index as a measure of productive potential breaks down. As further evidence in support of this theory, when yields of planted and managed natural stands are compared using published yield tables as the basis (Bennett 1970a, 1970b), we find that yields are nearly equal for comparable basal areas (table 4). Yields for plantation sites 70 and 80 (index age 25) should be matched with natural stand sites 93 and 105 (index age 50) respectively for a similar comparison.[3] Any difference favoring plantations relates to the fact that density control in the natural stand was not initiated until 15 to 20 years of age. Yields from unmanaged natural stands which originate from high-density regeneration will, as we have shown, be considerably lower than those for plantations.

Table 4.--Comparison of yields of planted and natural slash pine at age 30 on equivalent sites (adapted from Bennett 1970a and 1970b)[1]

Density class	Basal area	Yield per acre	
		Planted	Natural
		- - - Cubic feet - - -	
200	98	2,745	2,730
300	121	3,315	3,310
400	139	3,752	3,790
500	154	4,112	4,150

[1] Site 60 (index age 25) for plantations and site 80 (index age 50) for natural stands.

[3] We recognize, of course, that limiting vegetative competition in natural stands to the level experienced in old-field plantations might result in slightly higher site index readings for the natural sites, especially at low ages.

Yields in natural stands can equal those in plantations if density is controlled. Stand in foreground was precommercially thinned; stand in background was unthinned.

CONCLUSIONS

We conclude, based on its silvical characteristics, that slash pine can best be managed under an even-aged system. It can be naturally regenerated by seed tree or shelterwood methods. In either case, young stands are likely to be overstocked, and thinning at an early age is highly desirable. If this thinning is done at an early age, natural stands will have yields comparable to plantations on equivalent sites.

LITERATURE CITED

Bennett, Frank A.
1954. Reduction in growth of interplanted slash pine. USDA For. Serv. Southeast. For. Exp. Stn. Res. Notes 55, 2 p. Asheville, N. C.

Bennett, Frank A.
1960. Height growth pattern and thinning of slash pine (Pinus elliottii var. elliottii). J. For. 58:561-562.

Bennett, Frank A.
1970a. Variable-density yield tables for managed stands of natural slash pine. USDA For. Serv. Res. Note SE-141, 7 p., Southeast. For. Exp. Stn., Asheville, N. C.

Bennett, Frank A.
1970b. Yields and stand structural patterns for old-field plantations of slash pine. USDA For. Serv. Res. Pap. SE-60, 81 p., Southeast. For. Exp. Stn., Asheville, N. C.

Bennett, Frank A.
1971. The role of thinning and some problems in management of slash pine plantations. USDA For. Serv. Res. Pap. SE-86, 14 p., Southeast. For. Exp. Stn., Asheville, N. C.

Collins, Arthur B., III
1967. Density and height growth in natural slash pine. USDA For. Serv. Res. Pap. SE-27, 8 p., Southeast. For. Exp. Stn., Asheville, N. C.

Cooper, Robert W., and John H. Perry, Jr.
1956. Slash pine seeding habits. South. Lumberman 193(2417):198-199.

Cooper, Robert W.
1965. Slash pine (Pinus elliottii var. elliottii). In Silvics of forest trees of the United States. USDA For. Serv. Agric. Handb. 271, p. 458-463. Washington, D. C.

Forbes, R. D.
1930. Timber growing and logging and turpentining practices in the southern pine region. U. S. Dep. Agric. Tech. Bull. 204, 114 p. Washington, D. C.

Hodges, Charles S.
1969. Modes of infection and spread of Fomes annosus. Annu. Rev. Phytopathol. 7:247-266.

Keister, Thomas D., A. Bigler Crow, and Paul Y. Burns
1968. Results of a test of classical thinning methods in a slash pine plantation. J. For. 66:409-411.

Koenigs, J. W.
1971. Borax: Its toxicity to Fomes annosus in wood and its diffusion, persistence, and concentration in treated stumps of southern pines. Phytopathology 61:269-274.

Langdon, O. Gordon, and Robert P. Schultz
1973. Longleaf and slash pine. In Silvicultural systems for the major forest types of the United States. USDA For. Serv. Agric. Handb. 445, p. 85-89. Washington, D. C.

McCulley, Robert D.
1950. Management of natural slash pine stands in the flatwoods of south Georgia and north Florida. U. S. Dep. Agric. Circ. 845, 57 p. Washington, D. C.

McMinn, James W.
1965. Precommercial thinning in dense young slash pine of north Florida. For. Farmer 24(12):10-11.

Osborne, J. G., and V. L. Harper
1937. The effect of seedbed preparation in first-year establishment of longleaf and slash pine. J. For. 35:65-68.

Ross, E. W.
1970. Stump and soil temperatures in a slash pine stand and their relation to colonization by Fomes annosus. In Proceedings third international conference Fomes annosus. p. 121-125. USDA For. Serv., Washington, D. C.

Wakeley, Philip C.
1969. Single commercial thinnings in variously spaced slash and loblolly pine plantations. USDA For. Serv. Res. Pap. SO-48, 12 p., South. For. Exp. Stn., New Orleans, La.

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DA Forest Service Research Paper SE-148 June 1976

MIST BLOWER APPLICATION OF GUTHION® FOR CONE INSECT CONTROL IN SLASH PINE SEED ORCHARDS

by

Edward P. Merkel

Gary L. DeBarr

and

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MAY 4 1977

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MIST BLOWER APPLICATION OF GUTHION® FOR CONE INSECT CONTROL IN SLASH PINE SEED ORCHARDS

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Merkel and Yandle (1965) first reported that Guthion® (azinphosmethyl)[2] applied by mist blower effectively controlled Dioryctria spp. (Lepidoptera: Pyralidae: Phycitinae) and the slash pine seedworm, Laspeyresia anaranjada Miller (Lepidoptera: Olethreutidae), in cones of slash pine, Pinus elliottii Engelm. DeBarr and Merkel (1971) reported that mist blower applications of Guthion® also controlled Dioryctria spp. and the seedworm Laspeyresia ingens Heinrich in cones of longleaf pine, Pinus palustris Mill. This paper describes operational tests of this insecticide applied by mist blower primarily to prevent attacks by Dioryctria spp. larvae on second-year cones of slash pine. Additional data were obtained on the effectiveness of Guthion® in protecting maturing seeds in these cones from losses caused by the seedbugs Leptoglossus corculus (Say) (Hemiptera: Coreidae) and Tetyra bipunctata (H. - S.) (Hemiptera: Pentatomidae).

METHODS

Tests were conducted cooperatively with the International Paper Company in two of its seed orchards of slash pine--the Gateswood Seed Orchard, Baldwin County, Alabama, and the Dellwood Seed Orchard, Jackson County, Florida. Trees in these orchards averaged 14 years old, 10 in. (25.4 cm) d.b.h., and 38 ft (11.6 m) high.

The entire 16 acres (6.5 ha) of the Gateswood Seed Orchard and 25.5 acres (10.3 ha) of the Dellwood Seed Orchard were used for these tests. Because of the operational nature of the tests, the unsprayed area of each orchard was kept as small as possible. At Gateswood only 2.5 acres (1 ha) were left unsprayed, and at Dellwood only 3 acres (1.2 ha) were unsprayed.

---

[1]Presently employed as Manager of the Southern Tree Improvement Facility, Weyerhaeuser Company, Hot Springs, Arkansas.

[2]The chemical name of azinphosmethyl is O, O-dimethyl S(4-oxo-1, 2, 3-benzotriazin-3(4H)-ylmethyl) phosphorodithioate. Guthion® is Chemagro Corporation's trade name for this chemical.

In both orchards, a mist blower was used to apply Guthion as a 1-percent water emulsion without addition of a spreading or sticking agent. The mist blowers were calibrated to deliver the insecticide emulsion at the rate of 1 gallon (3.8 liters) per tree, or 50 gallons (189 liters) per acre. Dates of spray applications at the Gateswood and Dellwood Seed Orchards are given in table 1.

Table 1.--Dates on which Guthion was applied at Gateswood and Dellwood Seed Orchards, 1971-1973[1]

Gateswood Seed Orchard			Dellwood Seed Orchard		
1971	1972	1973	1971	1972	1973
July	May 4	May	Apr.	Apr.	Apr.
Aug.	May 30	June	May	May	May
	July	July	July	June	June
		Aug.	Aug.	July	July
				Aug.	Aug.

[1]Monthly applications from April through August were originally planned for both orchards, but, because of unforeseen circumstances, this schedule was followed only at the Dellwood Orchard in 1972 and 1973.

Experimental Design

In each orchard, 4 ramets of each of 8 clones (32 trees) were designated in the sprayed plot and 4 ramets of the same 8 clones were designated in the unsprayed plot. The same field-plot design was used in both seed orchards, but clones differed between orchards.

Because of the logistics of spraying and the need to minimize effects of spray drift on unsprayed trees, the treatments were not applied at random to individual ramets (trees) of the same clone, or to small blocks of trees. In our field-plot design, we assumed that the area effect was negligible and that clones were replicates for the following analysis of variance:

Sources of variation	Degrees of freedom	Estimated mean squares
Clones--replicates (C)	7	$\sigma^2 + 8\ \sigma^2_C$
Treatments (T)	1	$\sigma^2 + 4\ \sigma^2_{CT} + 32\ \theta^2_T$
Clone x Treatment interaction (C x T)	7	$\sigma^2 + 4\ \sigma^2_{CT}$
Error	48	σ^2

A mixed model was assumed in which clones were considered random effects and treatments fixed effects.

Evaluation of *Dioryctria* spp. Control

The effectiveness of Guthion for control of *Dioryctria* spp. coneworms was evaluated at cone harvest in mid-September of each year. All second-year cones were tallied and divided into two classes: (1) those that were undamaged by coneworms, and (2) those that were either actively infested at cone harvest or had been successfully attacked and killed earlier in the second year of development. The mature cones were harvested each fall with a tree-shaker; any sound or attacked second-year cones remaining on the tree were removed by hand to ensure a complete count of the total crop of mature cones. No assessment was made of attacks by *Dioryctria* spp. on first-year cones. Percentages of cones infested per tree were transformed to arcsin $\sqrt{\text{percentage}}$ and subjected to analysis of variance.

Dioryctria amatella (Hulst) was the only species reared from mature infested cones after harvest during the 3 years of these field tests. First-year cones with damage symptoms characteristic of *D. clarioralis* (Walker) were observed in both orchards. Another species, *D. abietella* (D. & S.), probably occurred also, but it was not positively identified.

Evaluation of Seedbug Control

Damage to mature seeds in apparently sound cones by the seedbugs *Tetyra bipunctata* and *Leptoglossus corculus* was evaluated by radiographic methods reported by DeBarr (1970). In 1971 and 1973, all seeds were extracted from cones harvested from the study trees. A sample of 500 uncleaned seeds (or all seeds if less than 500) was radiographed from each ramet. The percentages of seeds sound, empty, and damaged by seedbugs were determined from the radiographs.

It should be noted that *L. corculus* is multi-voltine and is capable of aborting first-year conelets, first-year ovules, and second-year ovules, in addition to damaging and destroying seeds in maturing cones (DeBarr and Ebel 1973). In these tests, however, control of *L. corculus* and *T. bipunctata* was determined only from the condition of mature seeds extracted from cones at harvest. Some seeds classified as empty from the radiographs may have been destroyed by seedbugs.

RESULTS

Dioryctria spp. Control

At Dellwood Seed Orchard, mean reduction in coneworm infestation on all clones as a result of spraying with Guthion® was 70 percent in 1971, 76 percent in 1972, and 84 percent in 1973 (table 2). At the Gateswood Orchard, the mean reduction in infestation as a result of spraying was 0 in 1971, 66 percent in 1972, and 69 percent in 1973. Coneworm attacks differed significantly among clones in all three test years at Dellwood and in 1971 and 1973 at Gateswood. The clone x treatment interaction was significant at Dellwood in all test years and at Gateswood in 1971.

In addition to reducing the percentage of maturing cones attacked by coneworms, spraying also increased the mean number of sound cones produced each year except 1971 at the Gateswood Orchard (table 3).

Table 2.--Mean percentages of coneworm-infested cones per clone on slash pines sprayed with Guthion and those unsprayed, Dellwood and Gateswood Seed Orchards, 1971-1973[1]

DELLWOOD SEED ORCHARD

Clone	1971		1972		1973	
	Sprayed	Unsprayed	Sprayed	Unsprayed	Sprayed	Unsprayed
	Percent					
CH-1	2.3	17.1	2.6	25.1	2.0	17.2
CH-10	7.2	36.7	5.1	60.0	5.4	49.3
CH-37	10.2	28.4	4.5	24.7	5.4	24.5
CH-38	1.7	4.0	2.7	4.3	.3	6.2
FA-14	7.3	20.3	10.2	17.2	2.2	20.1
FA-2	13.7	34.4	8.7	33.3	10.2	39.5
FA-6	3.9	6.0	6.0	8.7	2.3	14.1
FT-2	1.6	11.7	4.8	14.2	.6	30.0
Weighted mean[2]	6.0	19.8	5.6	23.4	3.6	25.1
	(P = 0.004)[3]		(P = 0.022)[3]		(P = 0.002)[3]	
Percent reduction[4]	70		76		84	

GATESWOOD SEED ORCHARD

B-1	4.8	10.1	3.9	25.9	4.2	23.7
FA-2	56.1	18.3	15.4	31.1	7.5	13.2
J-10	22.7	20.4	14.9	36.1	7.4	15.9
J-18	11.0	15.4	11.8	45.5	8.6	34.5
J-22	5.8	5.0	9.6	18.4	2.5	14.4
J-4	8.6	11.3	10.7	34.7	4.0	14.4
PR-2	4.0	7.7	10.0	42.1	6.2	27.1
S-3	12.0	5.2	12.3	25.7	7.6	14.2
Weighted mean[2]	15.6	11.4	11.1	32.2	6.0	19.5
	(P = 0.565)[3]		(P = 0.0005)[3]		(P = 0.002)[3]	
Percent reduction[4]	0		66		69	

[1]Each mean is the average of four ramets per clone.

[2]Each weighted mean = $\frac{\text{total numbers of infested cones}}{\text{total number of cones}} \times 100$ for 32 trees.

[3]P = probability of obtaining chance differences as large as these; observed treatment differences are therefore significant at the indicated probability levels.

[4]Percent reduction = $\frac{\text{weighted mean (unsprayed) - weighted mean (sprayed)}}{\text{weighted mean (unsprayed)}} \times 100$.

Table 3.--Mean number of sound cones produced on slash pines sprayed with Guthion and those unsprayed at Dellwood and Gateswood Seed Orchards, 1971-1973

Treatment	Dellwood Orchard			Gateswood Orchard		
	1971	1972	1973	1971	1972	1973
	Number					
Sprayed	222*	122†	231**	115	111**	241**
Unsprayed	141	79	97	130	49	139

Symbols indicate significantly more sound cones on the sprayed than on the unsprayed areas: † = 0.10 level, * = 0.05 level, ** = 0.01 level.

Seedbug Control (Dellwood Orchard)

In 1971 at Dellwood Orchard, seedbugs destroyed an average of 6.4 percent of the seeds harvested from unsprayed trees and only 2.2 percent of those from trees sprayed with Guthion®, a difference that was significant at the 0.05 level (table 4). However, there were no significant differences between sprayed and unsprayed trees in percentages of sound seeds or empty seeds. Differences in the percentages of empty seed among the eight clones were highly significant, perhaps because of inherent differences in selfing or other traits which result in empty seeds.

Table 4.--Mean percentages of slash pine seeds classified as sound, empty, and damaged by seedbugs on sprayed and unsprayed areas, Dellwood Seed Orchard, 1971 and 1973

Year and treatment	Seed classification		
	Sound	Empty	Damaged by seedbugs
	- - - - - - - - - Percent - - - - - - - - -		
1971			
Sprayed	88.1	9.7	2.2*
Unsprayed	85.1	8.5	6.4
1973			
Sprayed	96.0**	2.1**	1.9**
Unsprayed	75.8	12.2	12.0

Asterisks indicate significant difference between percentages for sprayed and unsprayed areas: * = 0.05 level, ** = 0.01 level.

In 1973 at Dellwood, seedbug damage to seeds averaged only 1.9 percent on sprayed trees and 12 percent on unsprayed trees. Yield of sound seed averaged 96 percent on sprayed trees and only 75.8 percent on unsprayed trees. Differences between treatments in the percentages of sound, empty, and damaged seeds were significant at the 0.01 level.

In 1973, there were also significant differences among clones in the percentages of sound, empty, and seedbug-damaged seeds. In the unsprayed area, seedbugs damaged 21.6 percent of the seeds from the most susceptible clone and only 3 percent of those from the least susceptible clone.

Seedbug Control (Gateswood Orchard)

In 1971 at Gateswood Orchard, there was no significant difference between the amount of seedbug-damaged seeds from sprayed (3.5 percent) and unsprayed (4.8 percent) trees (table 5). However, the yield of sound seed was significantly different between treatments at the 0.05 level.

Table 5.--Mean percentages of slash pine seeds classified as sound, empty, and damaged by seedbugs on sprayed and unsprayed areas, Gateswood Seed Orchard, 1971 and 1973

Year and treatment	Seed classification		
	Sound	Empty	Damaged by seedbugs
	- - - - - - - - - Percent - - - - - - - - -		
1971			
Sprayed	86.0*	10.5	3.5
Unsprayed	83.3	11.9	4.8
1973			
Sprayed	82.0	11.4	6.6**
Unsprayed	76.3	12.3	11.4

Asterisks indicate significant difference between percentages for sprayed and unsprayed areas: * = 0.05 level, ** = 0.01 level.

In 1973 at Gateswood, seedbug damage averaged only 6.6 percent on sprayed trees and 11.4 percent on unsprayed trees, a difference that was significant at the 0.01 level. Yield of sound seeds was not increased significantly by the Guthion® sprays: 82.0 percent were sound on the sprayed trees and 76.3 percent were sound on the unsprayed trees.

In 1973, there were also significant differences among clones in the percentages of sound, empty, and seedbug-damaged seeds. In the unsprayed area, seedbugs damaged 21.1 percent of the seeds from the most susceptible clone and 3.8 percent of those from the least susceptible clone.

DISCUSSION

For these operational tests of Guthion®, five monthly applications, from April through August, were originally scheduled each year because (1) the multivoltine Dioryctria spp. in this area of the South attack maturing slash pine cones almost continuously from April through cone harvest and (2) Guthion® residues will not ordinarily remain toxic for more than 3 weeks. Only at Dellwood Orchard in 1972 and 1973 was this schedule followed, and it was at this orchard during these 2 years that the greatest reduction in coneworm infestation occurred. Protection from seedbug losses was also highly effective in this orchard during 1973.

Because of differences in timing, it was not possible to compare the effectiveness of the spray schedules in the two orchards during the same year. However,

it is noteworthy that applying Guthion® four times during a season resulted in comparable reductions in coneworm infestations at the two orchards--69 percent at Gateswood in 1973 and 70 percent at Dellwood in 1971. Furthermore, it was surprising that the three poorly timed applications at Gateswood in 1972 resulted in a 66-percent reduction in coneworm infestation, whereas four applications the following year in the same orchard resulted in only a slightly higher reduction--69 percent.

Southwide research on the total impact of insects on seed orchard production is currently underway. This research should provide a sounder basis for timing insecticide applications to coincide with those periods when cones are most susceptible to seed losses, thus possibly reducing the number of applications needed per year.

DeBarr and others (1972) reported that, in two out of three slash pine seed orchards in an insecticide test, cone infestation by Dioryctria spp. varied significantly among the five clones in the study. In the present tests, significant differences among clones occurred in coneworm attack and seedbug damage, and the clone x treatment interaction was also significant. These results emphasize the need for including clones as a source of variation when designing and analyzing the results of tests on insect control in seed orchards and for further research on host selection mechanisms.

Although these tests evaluated attacks by Dioryctria spp. and seedbugs only on second-year cones and in mature seeds, the reader should be aware that first-year female strobili can often suffer as much or more damage by insects as can maturing cones (Ebel 1961; Merkel 1961; Ebel and Yates 1974). Merkel (1964) reported that first-year cones of slash pine were completely protected from Dioryctria spp. attack by hydraulic spraying with Guthion® on April 24, May 4, and May 29. DeBarr and Merkel (1971) also found that attacks on first-year cones of longleaf pine between early April and September could be reduced by 94 percent with mist blower applications of Guthion® in April, May, and June. Thus, the five monthly applications of Guthion® reported here probably also protected the first-year cones of slash pine from coneworm attack during the same period.

This publication reports research involving pesticides. It does not contain recommendations for their use nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

LITERATURE CITED

DeBarr, G. L.
1970. Characteristics and radiographic detection of seed bug damage to slash pine seed. Fla. Entomol. 53:109-117.

DeBarr, G. L., and B. H. Ebel
1973. How seedbugs reduce the quantity and quality of pine seed yields. Twelfth South. For. Tree Improv. Conf. Proc. 1973:97-103.

DeBarr, G. L., and E. P. Merkel
1971. Mist blower spraying of longleaf pine for cone and seed insect control. USDA For. Serv. Res. Pap. SE-76, 7 p. Southeast. For. Exp. Stn., Asheville, N. C.

DeBarr, G. L., E. P. Merkel, C. H. O'Gwynn, and M. H. Zoerb, Jr.
1972. Differences in insect infestation in slash pine seed orchards due to phorate treatment and clonal variation. For. Sci. 18:56-64.

Ebel, B. H.
1961. Thrips injure slash pine flowers. J. For. 59:374-375.

Ebel, B. H., and H. O. Yates III
1974. Insect-caused damage and mortality to conelets, cones, and seed of shortleaf pine. J. Econ. Entomol. 67:222-226.

Merkel, E. P.
1961. A study of losses in the 1960 slash pine cone crop. USDA For. Serv. Southeast. For. Exp. Stn. Res. Notes 164, 2 p. Asheville, N. C.

Merkel, E. P.
1964. Hydraulic spray applications of insecticides for the control of slash pine cone and seed insects. U.S. For. Serv. Res. Note SE-9, 7 p. Southeast. For. Exp. Stn., Asheville, N. C.

Merkel, E. P., and D. O. Yandle
1965. Mist blower applications of insecticides for cone insect control on slash pine. U.S. For. Serv. Res. Note SE-52, 4 p. Southeast. For. Exp. Stn., Asheville, N. C.

Merkel, Edward P., Gary L. DeBarr, and Claude H. O'Gwynn
1976. Mist blower application of Guthion® for cone insect control in slash pine seed orchards. USDA For. Serv. Res. Pap. SE-148, 8 p. Southeast. For. Exp. Stn., Asheville, N. C.

From 1971 through 1973, a 1-percent water emulsion of Guthion® (azinphosmethyl) was applied by mist blowers to slash pine seed orchards in Florida and Alabama at the rate of 1 gallon per tree. Its effectiveness was evaluated against Dioryctria spp. coneworms and the seedbugs Leptoglossus corculus and Tetyra bipunctata. Reduction in coneworm infestations of mature cones ranged from 0 with only two applications per year to 84 percent with five monthly applications from April through August. Results also showed that seed losses to seedbugs can be reduced significantly, particularly with the five monthly applications.

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USDA Forest Service Research Paper SE-149 June 1976

Moisture Content of Wood Components in Three Low-Cost Houses

by

John E. Duff

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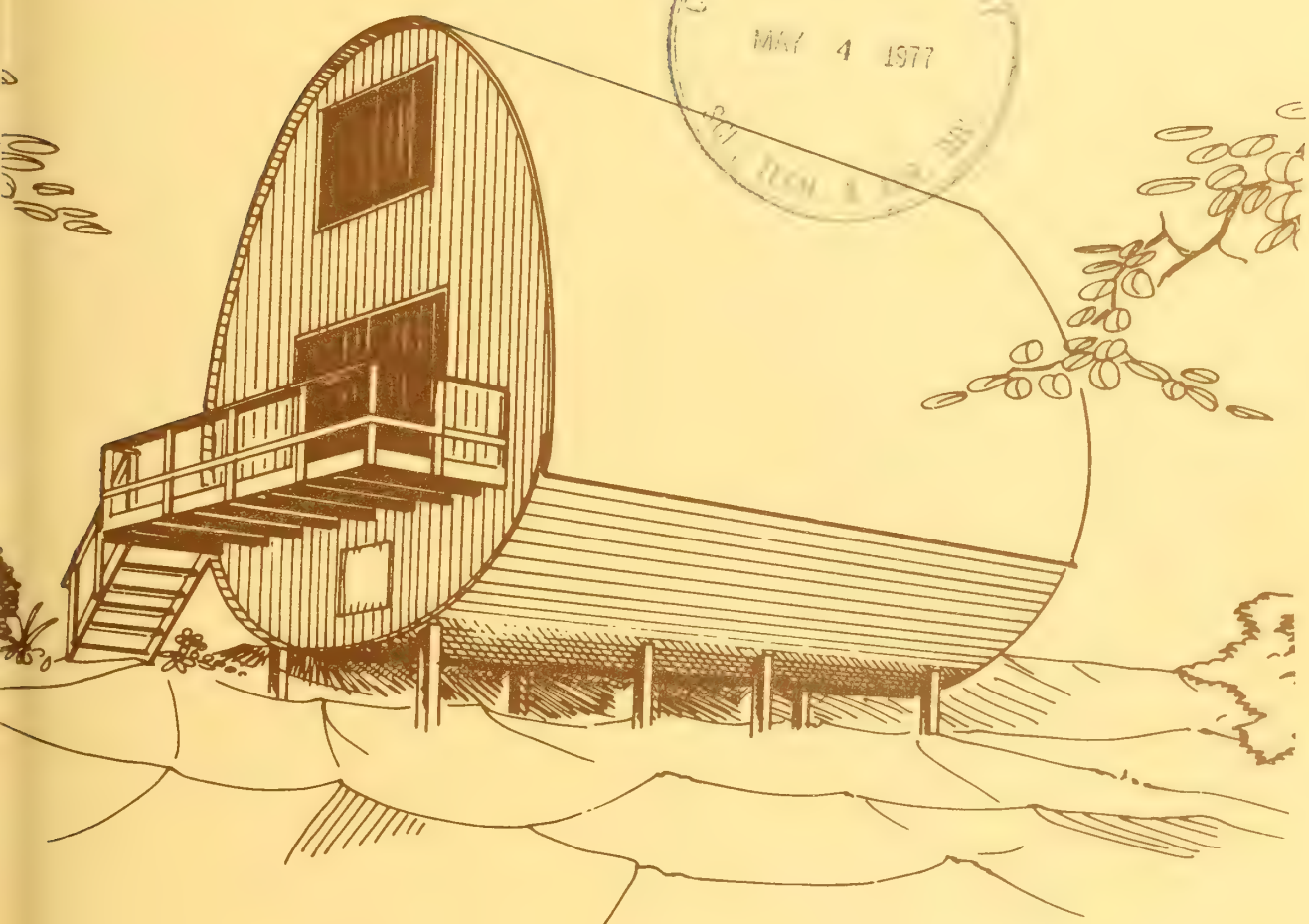

U.S. Department of Agriculture
Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Moisture Content of Wood Components in Three Low-Cost Houses

by

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Several of the designs developed for low-cost homes by the Southeastern Station's Housing Research Unit at Athens, Ga., call for unconventional uses of wood.[1] In an effort to reduce building costs, the various wood components in these homes were designed to serve multiple functions. For example, in the round house (Plan FS-SE-5), a single thickness of 2 by 8 softwood planks not only serves as a load-supporting exterior wall but also provides the finished surfaces of the interior and exterior walls and serves as wall insulation. Although design load stability and structural integrity of the wood components were carefully considered in all of the designs, the effects of interior and exterior temperature and moisture on these components are difficult to predict without actual field tests. Such tests are necessary to determine if any of the unusual uses of wood in these homes will result in trapped moisture that could lead to excessive dimensional change or, in extreme cases, to wood decay. Moisture contents and temperatures were therefore recorded for several months in various wood components of three of these low-cost homes--the pole-frame house (FS-SE-3), the tubular house (FS-SE-4), and the round house--built in North Carolina. Results of that study are reported here.

METHODS

Construction of the Low-Cost Houses

The three low-cost houses selected for this study were built in the Coastal Plain of North Carolina at Hope Mills by Mr. Tom Waring of Pioneer Homes. Because the designs were new, the structures were constructed under a Federal Housing Administration program for experimental housing. All of the houses were built on relatively flat, sandy sites, and each was privately owned and occupied during the study.

In constructing the pole-frame house (fig. 1), poles that had been pressure-treated with copper, chromium, and arsenate preservatives were used for the foundation and as supports for the roof load. The nonload-bearing interior and exterior walls were prefabricated in 4- by 8-foot prefinished stress-skin panels 1-½ inches thick. Two-inch insulation batts with an interior vapor barrier were

[1]Anderson, L. O., and Harold F. Zornig. 1969. Designs for low-cost wood homes. USDA For. Serv., Washington, D. C., 28 p. (This booklet, which contains brief descriptions and floor plans of the three homes discussed in this Research Paper, is still available in limited quantities from the Southeastern Forest Experiment Station, P. O. Box 2570, Asheville, N. C. 28802).

wedged in the panel cavity during manufacture. The pole-frame house was located on a sloping, well-drained, semishaded lot. It was heated with electric baseboard heat in winter and not air-conditioned in summer.

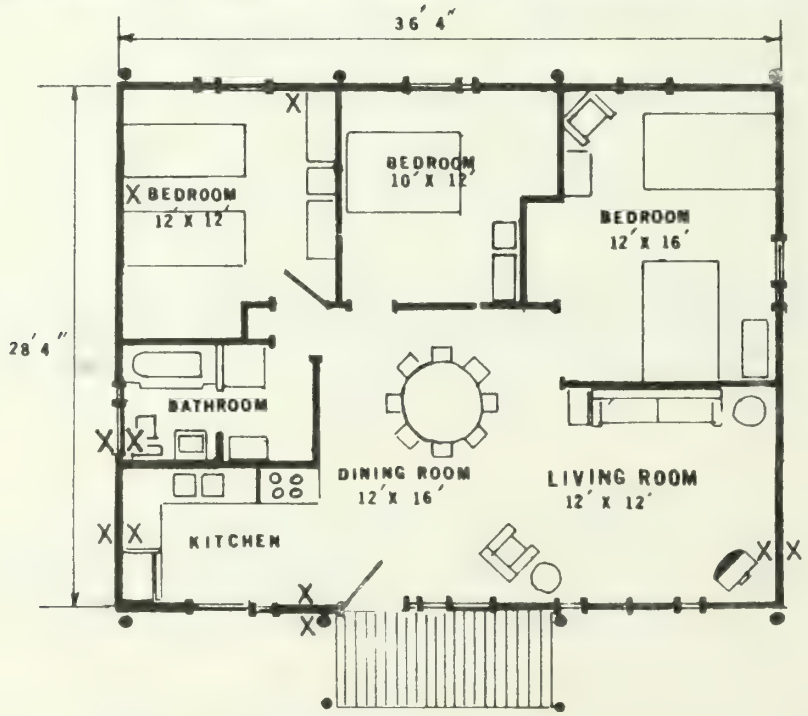

Figure 1.--Exterior view of the pole-frame house and diagram of sensor locations (X).

The tubular house (fig. 2) was constructed on 6- by 6-inch posts pressure-treated with copper, chromium, and arsenate preservatives. The walls were constructed of 2- by 6-inch tongue-and-grooved decking of southern pine that was nailed completely around four elliptical ribs of glue-laminated wood. The curved walls enclosing the two floors of living area were insulated on the exterior side with 1 inch of polyurethane foam (2 lb/ft^3) applied at the building site by a commercial operator. This foam, which was then covered with two coats of an aluminum-filled asphalt emulsion, served as insulation and a vapor barrier. The bottom third of the walls, which enclosed a storage area below the first floor, was not foamed, but latex paint was applied to the exposed decking. Both end-walls were composed of 3/8-inch exterior plywood nailed onto 2- by 4-inch stud framing and were insulated with conventional batt insulation of fiberglass. The house was heated with electric baseboard strip heaters and air-conditioned with a 12,000-Btu window unit.

The round house (fig. 3), which was constructed on a flat site, rested on a round concrete slab with conventional perimeter insulation and vapor barrier. A wood member pressure-treated with copper, chromium, and arsenate preservatives was fixed along the slab perimenter to serve as a nailing base for the single thickness of rough-sawn 2- by 8-inch southern pine planks in the exterior wall. The edges of these planks were joined in slots by a hardboard spline. This plank wall supported a system of rough-sawn 4- by 6-inch beams radiating from the center of the structure. The roof consisted of 1- by 6-inch tongue-and-grooved decking of southern pine sprayed with polyurethane foam (2 lb/ft^3) to a depth of 1 inch. Aluminum-filled asphalt emulsion was then applied to the foam for weather protection. The structure was heated and air-conditioned with a heat pump.

Moisture and Temperature Sensors

Moisture content of various wood components in the three houses and of the free air space in the wall insulation of the pole-frame house was measured with wood moisture probes.[2] These probes consisted of small strips of wood (0.07 by 0.07 by 0.75 inch) coated on two opposite faces with conductive silver paint. Moisture content was indicated as a function of the electrical resistance of the wood between the two silver electrodes. Temperature of the wood components was measured with conventional copper-constantan thermocouples adjacent to the wood moisture probes.

Probes located in wood measured the moisture content of the wood around the probe. Probes placed in the air indicated the equilibrium moisture content of the air near the probe.

Each pair of sensors was installed with a three-lead socket mounted to the surface of the wood components (fig. 4). A three-pronged jack connected the socket to a resistance-type moisture meter and a thermocouple potentiometer.

In the pole-frame house (fig. 1), the sensors were located only within the wall panels near the interior and exterior surfaces. In the tubular house (fig. 2), the sensors were located in the exposed decking on the underside, in the upper decking under the foam, and in the supporting ribs inside the structure.

[2] Duff, J. E. 1966. A probe for accurate determination of moisture content of wood products in use. U.S. For. Serv. Res. Note FPL-0142, 10 p. For. Prod. Lab., Madison, Wis.

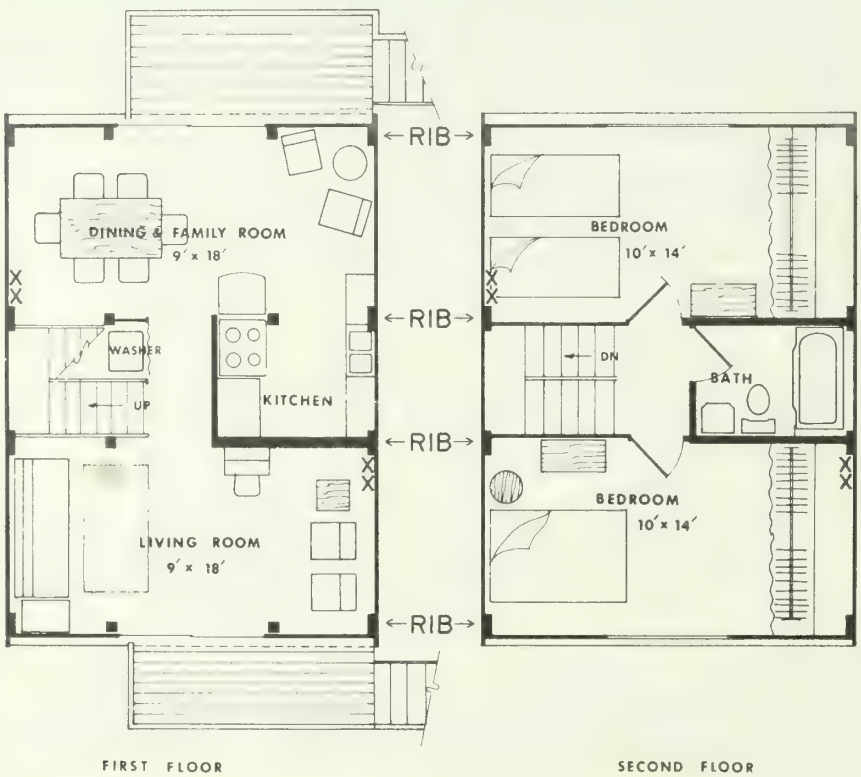

Figure 2.--Exterior view of the tubular house and diagram of sensor locations (X).

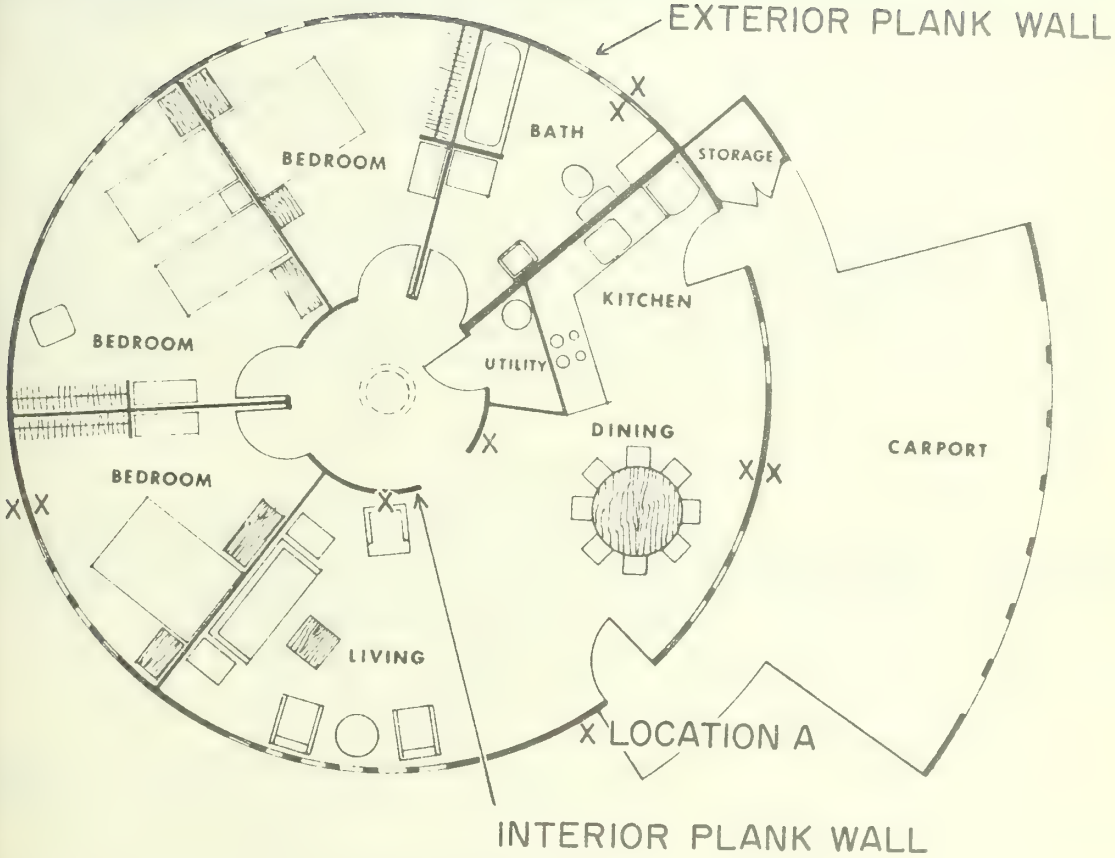

Figure 3.--Exterior view of the round house and diagram of sensor locations (X).

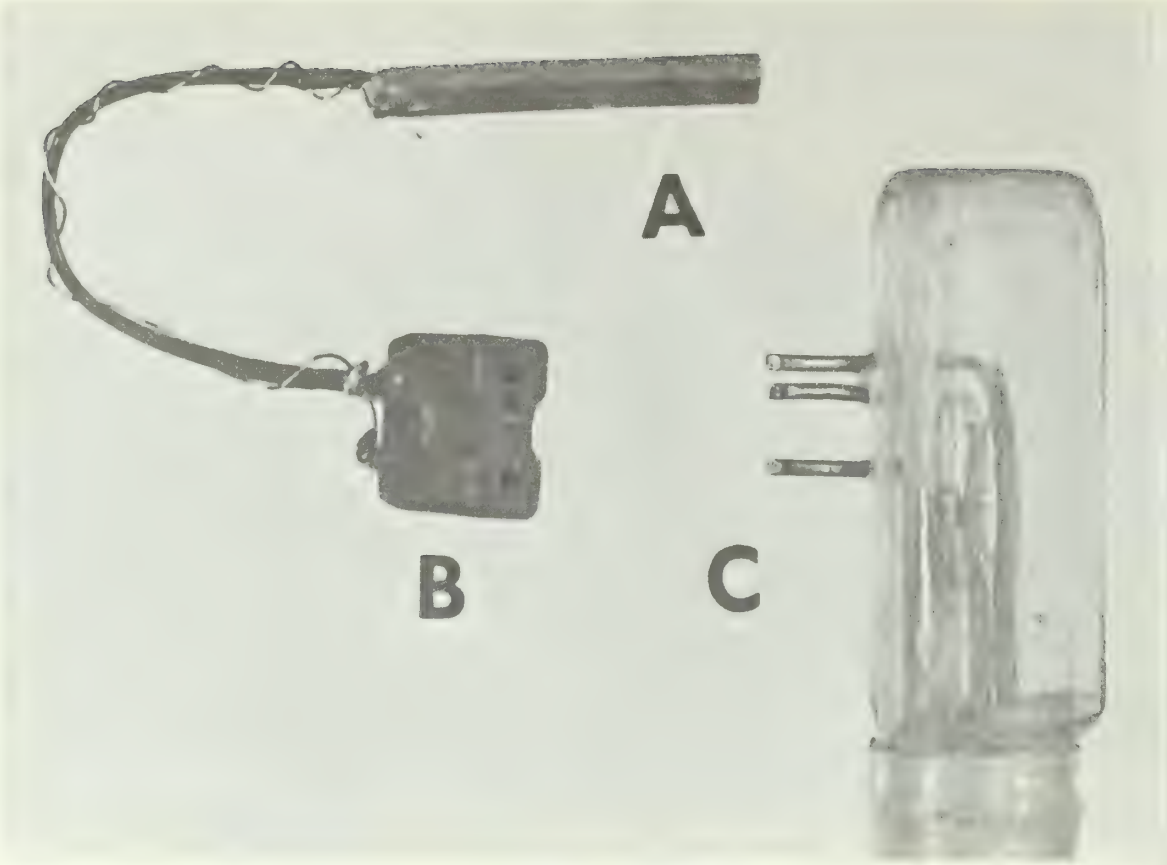

Figure 4.--(A) Moisture probe and thermocouple, (B) female socket, (C) three-pronged jack connected to moisture meter and thermocouple potentiometer (not shown).

In the round house (fig. 3), the sensors were installed in the roof decking under the foam and in the interior plank walls near the center of the structure. In this house, sensors were also located 4 feet above the floor in the exterior plank walls; measurements were taken near the interior and exterior surfaces of exposed planks and near both surfaces of a plank protected by the carport. An additional sensor was installed 6 inches from the bottom end of an exposed plank near the front door in the exterior wall (fig. 3, location A).

Experimental Procedure

After all the sensors were installed, moisture and temperature measurements were taken at monthly intervals from October 1969 through December 1970 by Mr. J. G. Simmons, Chief Inspector, Federal Housing Administration, Greenville, N. C. The tubular and round houses were occupied by families throughout the study, whereas the pole-frame house was occupied only during the final 11 months.

Monthly readings from the various moisture sensors at corresponding locations throughout a structure were corrected for temperature. Temperature correction was necessary to adjust the moisture readings to a calibration temperature of 70° F. Corrected moisture readings were averaged and plotted for analysis. For example, data from the various sensors near the interior surface of the wall panels of the pole-frame house were averaged each month and plotted as a single point.

RESULTS AND DISCUSSION

The Pole-Frame House

Wall Panels Near Interior Surface

The walls of the pole-frame house consisted of 1½-inch-thick sandwich panels insulated with a 2-inch insulation batt of fiberglass with an integral tar-base vapor barrier on the interior side. A time plot of the moisture conditions between the interior paneling and the vapor barrier shows that this air space remained relatively dry during the study except for the month of October, when the moisture level increased to about 13 percent (fig. 5).

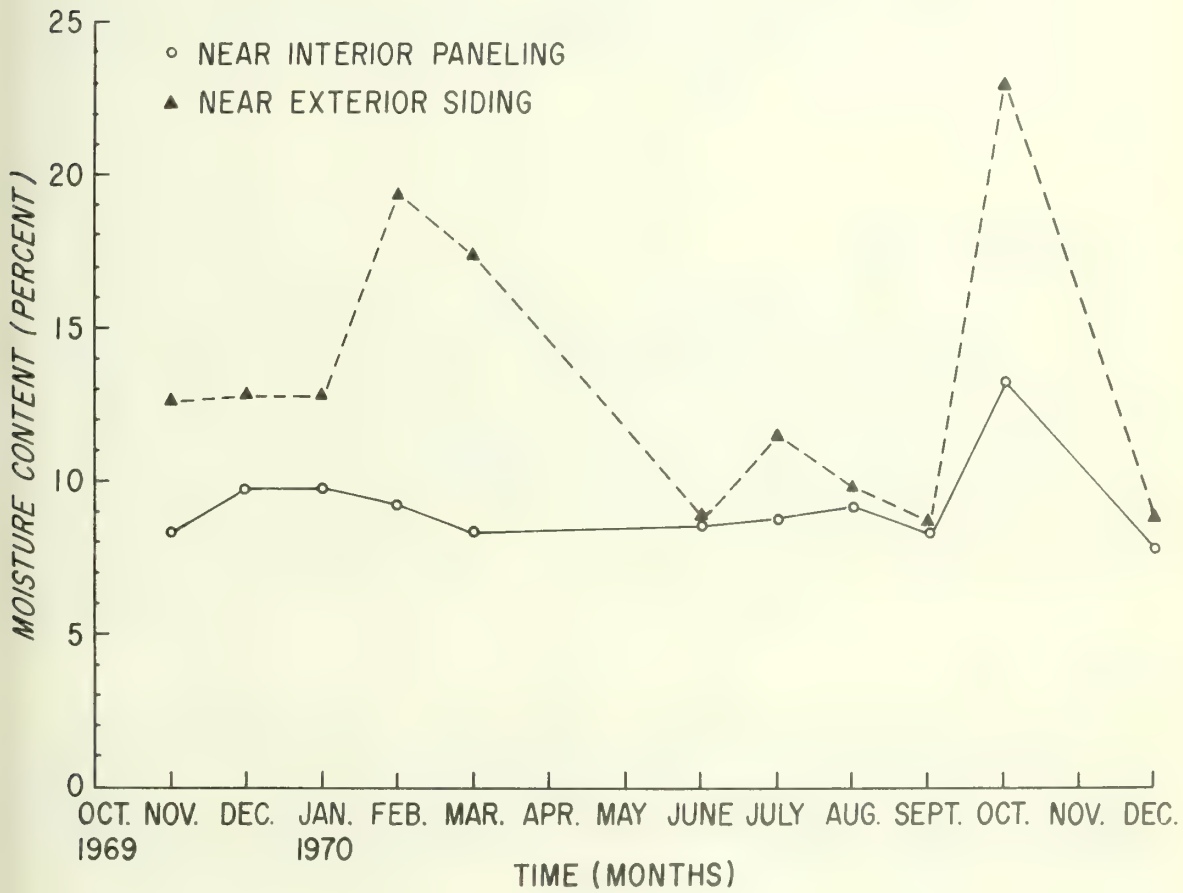

Figure 5.--Time plot of average moisture conditions near the interior and exterior surfaces within the wall panels of the pole-frame house.

Wall Panels Near Exterior Surface

In contrast, the moisture conditions of the air space between the wall insulation and the plywood siding were notably higher (fig. 5). Moisture in this area did not exceed 13 percent during the fall of 1969 while the house was unoccupied and unheated. However, when the house was occupied in January, moisture increased to almost 20 percent and then decreased with the approach of the warmer spring weather. Moisture in this part of the wall rose again in the fall, reading a high of 23 percent in October and subsequently dropping to about 9 percent in December.

The higher moisture in the outer portions of the walls during the cooler fall and winter months was probably due to leakage of interior water vapor around the edges of the vapor barrier on the insulation batts. These batts were wedged into the open spaces of the sandwich panels but were not overlapped on the edges of the studs. This type of leakage was not considered serious in the mild winter climate of Hope Mills, N. C., but could cause moisture condensation in climates where prolonged cold spells are commonplace.

The Tubular House

Roof Decking Under Foam

One of the major questions concerning the tubular house was whether moisture would change greatly in the 2-inch decking overlaid with 1 inch of polyurethane foam. As indicated by the four sensors in this area, the moisture content was less than 12 percent when this decking was installed in the fall of 1969, but it decreased to a low of 8 percent by early spring of 1970 (fig. 6). With the approach of summer, the moisture increased, reading a maximum of about 11 percent in the fall before decreasing to an overall low of about 7 percent in December. Thus, the data clearly indicate that the wood decking overlaid with foam can be expected to remain dry with only minor seasonal variation in moisture contents.

Exposed Decking

Moisture content of the exposed decking adjacent to the unheated, unvented storage area in the lower third of the house was expected to be higher than that of the foamed decking. In most cases, it averaged about 2 percent higher (fig. 6). Moisture content of this decking was a little over 12 percent at the beginning of the study and decreased to a low of 10 percent in early summer. During the summer, the moisture conditions increased, reaching a peak of 17 percent in October. This high reading resulted because the data were measured after a rain. With the approach of winter, the moisture dropped to between 10 and 11 percent.

Thus, the data indicate that moisture conditions in the exposed decking were not excessive. This decking can be considered as remaining essentially dry and decay-free during the study.

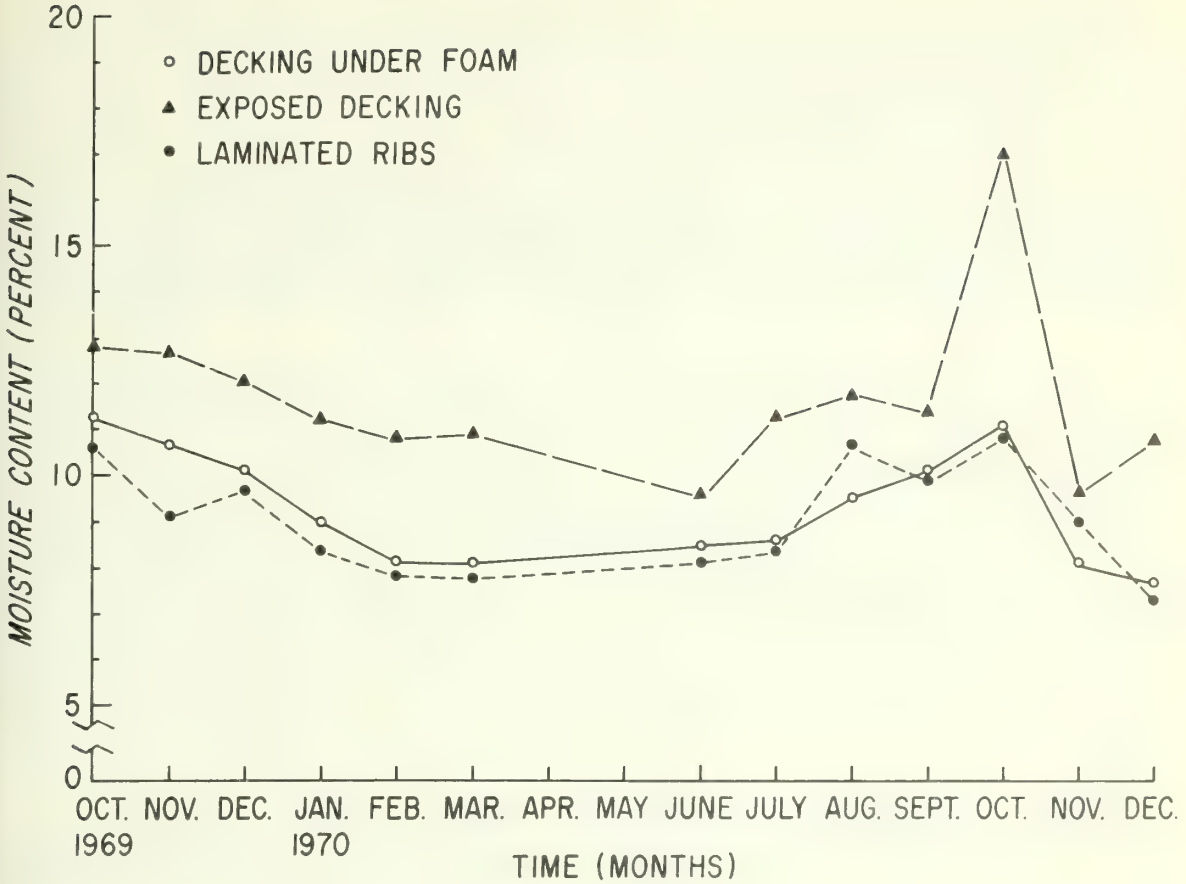

Figure 6.--Time plot of average moisture conditions in the decking covered with foam, the exposed decking, and the laminated ribs of the tubular house.

Laminated Ribs

Moisture variation in the more massive components of the house was determined by instrumenting the four laminated ribs inside the structure. As expected, the moisture content closely paralleled that of the foamed decking (fig. 6). Moisture content of these ribs was 10½ percent when measurements began in 1969 and reached a low of about 8 percent in the early spring of 1970. It increased to a peak of about 11 percent in the fall before dropping to an overall low of 7 percent in the early winter.

Thus, the data clearly show that the larger structural members inside the tubular house will remain dry, dimensionally stable, and decay-free during service.

Interior Plank Wall and Roof Decking

Moisture conditions in the interior plank wall and in the foamed roof decking of the round house were almost identical; in both, maximum moisture content was about 9½ percent and the minimum was between 6 and 7 percent (fig. 7). Although moisture in the interior plank wall was expected to be low during the winter when heating was used, it remained low even during the summer months.

As with the tubular house, there was a question about moisture conditions in the roof decking covered with foam. Theoretically, the wood decking should become drier because the major temperature drop or gradient that usually exists across insulated roof sections during winter is expected to occur across the insulation and not the decking. Thus, moisture buildup that is associated with decreasing temperature gradients should occur in the foam instead of the decking. If so, the decking would be subjected to a warm and dry environment during the winter and would subsequently remain dry. Evidently, this effect was responsible for the dryness maintained by the roof decking in both the round and tubular houses (figs. 6 and 7).

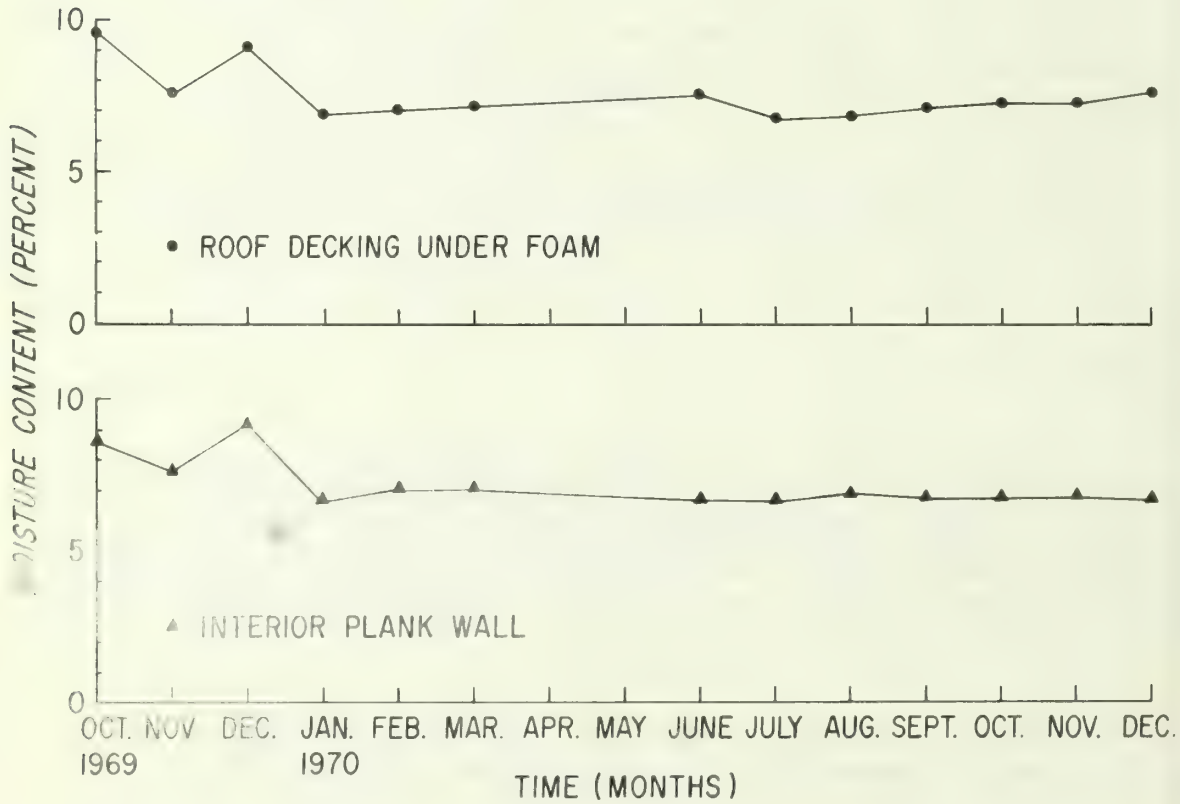

Figure 7.--Time plot of average moisture conditions in the roof decking covered with foam and the interior plank wall of the round house.

The roof decking was expected to increase slightly in moisture content during summer because interior relative humidity is usually higher during that season than in winter. However, apparently because of the flat roof design and the lack of normal roof ventilation, the roof decking was warmed by the summer sun during the daylight hours and remained dry throughout the season (fig. 7).

Thus, moisture content of the interior plank walls and the roof decking remained consistently low during summer and winter. This uniformity indicates that these wood components will remain dimensionally stable under both summer and winter extremes.

Exterior Plank Wall at Mid-Height

Moisture conditions were measured at mid-height inside exposed planks in the exterior wall and in a plank protected by the carport (fig. 8). As expected, the interior portion of exposed planks remained relatively dry during the study. The outer portions of these planks also remained relatively dry (8 to 10 percent) except when the monthly measurements were taken soon after a rain. Such measurements caused high moisture readings twice during the study (14 percent in February of 1970 and 29 percent in October of that year), although the walls, of course, became wet after each rain. The data indicate that the wetting of the exterior wall surfaces was temporary. The possibility of decay can be minimized by changes in the design specifications of the round house, as discussed later in this paper.

The exterior plank wall protected by the carport did not become wet from the rain. In general, moisture conditions in this area of the wall closely paralleled those near the exterior surface of exposed planks, although moisture increases after rains were much smaller (fig. 8).

Bottom of Exterior Plank Wall

Moisture conditions were also measured 6 inches from the bottom of an exposed plank next to the front door in the exterior wall (see fig. 3, location A). Because the roof was designed without gutters or any overhang except at the carport and entrances, it drained at this point onto the wall surface and subsequently saturated the lower third of the wall during any appreciable rain. This area could be further affected by water splashing from the ground. The sensor was therefore installed to determine if this lower wall area would dry out between rains after being saturated.

Although this wall area was often directly wetted by roof drainage, it subsequently dried to a much lower level of moisture (fig. 9). Recorded moisture content reached 27 percent in October 1970 when measurement was taken immediately after a rain, but it returned to much lower levels during the last 2 months of the study.

In general, the moisture level was slightly higher in the lower wall than at mid-height on the exterior wall (fig. 9). This condition arose because the lower area was close to the ground, where drying conditions were poor as a result of ground moisture and nearby shrubbery.

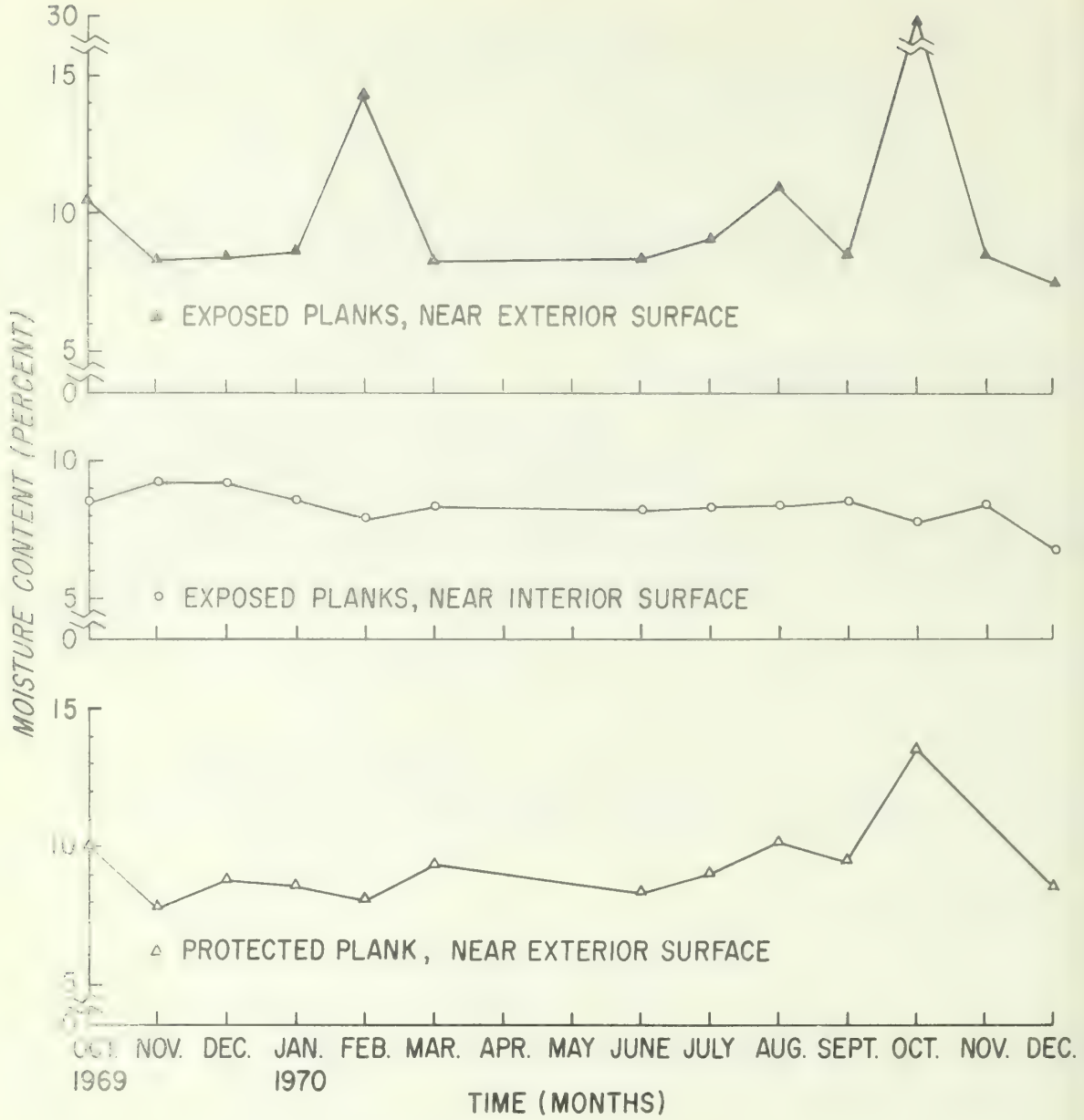

Figure 8.--Time plot of average moisture conditions near the interior and exterior surfaces of exposed planks in the exterior wall of the round house and near the exterior surface of a wall plank protected by the carport. All measurements were made at mid-height of the planks.

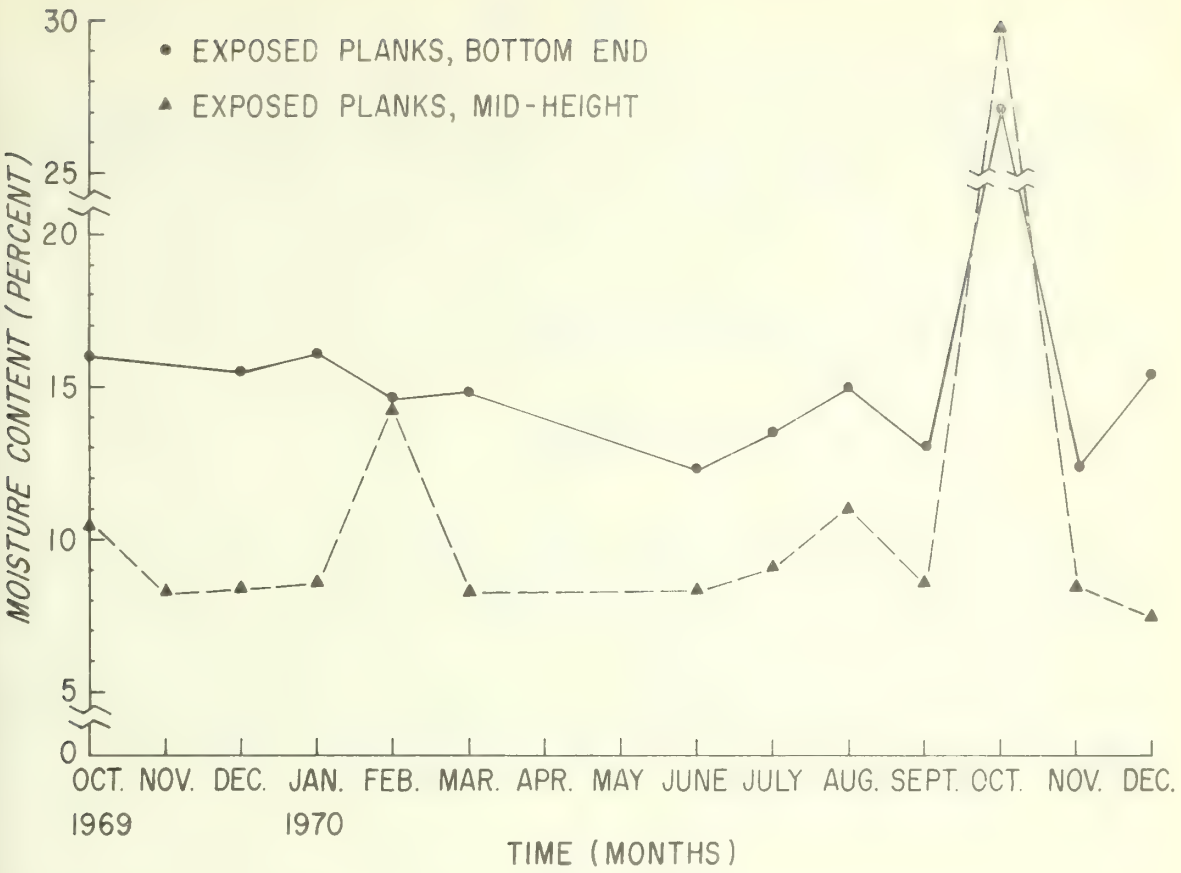

Figure 9.--Time plot of moisture conditions 6 inches from the bottom end of an exposed exterior plank near the front door of the round house. Included for comparison is the time plot of measurements taken near the exterior surface of exposed planks at mid-height.

RECOMMENDATIONS

During this 15-month study, no serious moisture hazards existed in the various wood components of two of the three low-cost houses built in Hope Mills, N. C. On the basis of the data collected, several recommendations can be made to reduce the possibility of such hazards arising in other homes built from these designs, especially those built in more severe climates than found in Hope Mills.

Pole-Frame House

Moisture contents in the exterior side of the wall panels were higher in late fall and winter than in summer. This fluctuation probably arose because some moisture from the interior of the structure leaked around the vapor barrier and into the outside wall sheathing during the cooler months. Such leakage can be minimized by tightly fitting the vapor barrier around all stud members of each sandwich panel. The tabs of the batt insulation should overlap on the edges of the framing members, and the vapor barrier should, of course, be placed on the interior side of the panel.

Tubular House

Moisture in the wood decking under the polyurethane foam decreased after installation and never rose higher than 11 percent. Therefore, this decking should be installed in a dry condition (10 to 12 percent moisture content) if checks and joint separation are to be avoided. Such decking can be expected to remain dimensionally stable during use, even under seasonal extremes.

Moisture content in the exposed decking was generally about 2 to 3 percentage points higher than in the foamed decking but posed no serious hazard. This decking should also be installed in a dry condition.

Round House

The exterior surfaces of the wall planks at mid-height and at the bottom were saturated during rain. High moisture conditions at the bottom of these planks can be reduced by providing gutters on an overhanging roof so that roof drainage is directed away from the exterior wall. Prior to installation, the lower ends of these planks should be dipped for 3 minutes in pentachlorophenol solution, a commercially available water-repellent. Furthermore, shrubbery should not be planted too close to the exterior wall. A space of 1½ to 2 feet between the wall and any shrubs will provide sufficient air circulation to dry the lower wall surface after a rain.

Duff, John E.

1976. Moisture content of wood components in three low-cost houses. USDA For. Serv. Res. Pap. SE-149, 14 p. Southeast. For. Exp. Stn., Asheville, N. C.

Moisture contents were recorded for 15 months in the wood components of three low-cost houses designed by the Southeastern Station at Athens, Ga., and built in Hope Mills, N. C. In the pole-frame house (Plan FS-SE-3) and the tubular house (Plan FS-SE-4), moisture contents were not hazardously high for homes built in mild climates. The highest level recorded (almost 30 percent) was temporarily induced by rainfall on the exterior plank siding of the round house (Plan FS-SE-5). Modifications in the design specifications for the round house are recommended to overcome this problem.

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SDA Forest Service Research Paper SE-150 August 1976

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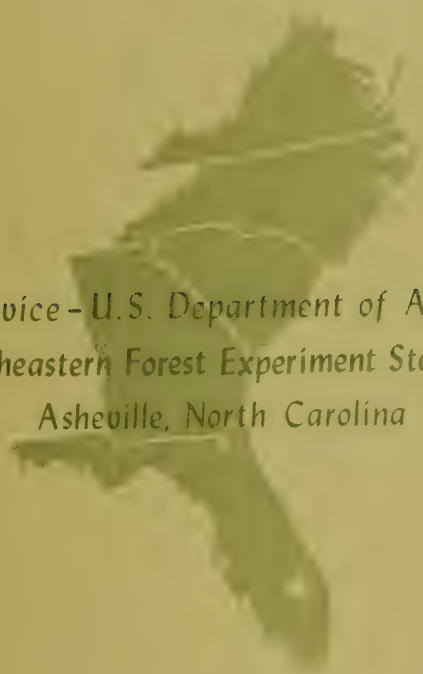

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Acknowledgment of helpful services is extended to the following: T. R. Love, C. R. Robinson, and L. E. Andrews, USDA Forest Service, for locating soil pits and writing the initial soil profile descriptions; Dr. R. A. Klawitter, USDA Forest Service, for writing the study plan; C. E. Young, Jr., formerly employed by the Southeastern Forest Experiment Station, for assisting with sampling techniques and calculations of data; and Bobby Long, USDA Soil Conservation Service, for reclassifying and describing the soils in the same way that he did in his recently completed soil survey of Berkeley and Charleston Counties, S. C.

Moisture Characteristics of Some Coastal Plain Soils on the Francis Marion National Forest

by

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and

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Abstract.--Twenty-one soil pits representing 10 soil series were established on the Francis Marion National Forest in Berkeley and Charleston Counties, S. C. Pits were primarily on very poorly drained and poorly drained soils, but somewhat poorly drained, moderately well-drained, and well-drained soils were each represented by a single soil pit. Soil physical properties that affect the storage and availability of water were evaluated, and data on saturated porosity, moisture at various tensions, available moisture by horizons, and bulk density are presented.

A summary and discussion of soil properties are provided for foresters and other resource managers, and detailed information is given for hydrologists and soil scientists working with forest soils of the Lower Coastal Plain of South Carolina. General soil moisture characteristics are presented. Where precise estimates of the available moisture storage capacity and other soil properties are needed for a particular site or location, soil samples should be collected and analyzed at a laboratory.

Keywords: Saturated porosity, available moisture, bulk density.

Watershed managers and other specialists need to know soil moisture characteristics to design drainage systems, water retention facilities, and flood control systems. In addition, reliable soil moisture data are useful guides to: the potential of soils to store rainfall, the amount of soil moisture available for plant use, and the amount of rainfall or irrigation water needed to attain field capacity when soils are dry.

Our paper provides information on moisture characteristics of 10 soil series under forest conditions on the Lower Coastal Plain of South Carolina. Lutz (1970) provided similar information for North Carolina soils. Steward and others (1963) reported on the moisture characteristics of representative Florida soils. Long and others (1963) listed moisture characteristics of some Lower Coastal Plain soils of Georgia and South Carolina, but their publication did not include the soil types we studied.

METHODS

The soils studied are within the boundaries of the Francis Marion National Forest; 19 soil pits were located in Berkeley County and 2 pits in Charleston County, S. C. (fig. 1). The study was concentrated upon soils classified as very poorly drained and poorly drained, but soils classified as somewhat poorly drained, moderately well drained, and well drained were also represented by a single pit for each drainage class. The parent materials of all soils are coastal marine sediments.

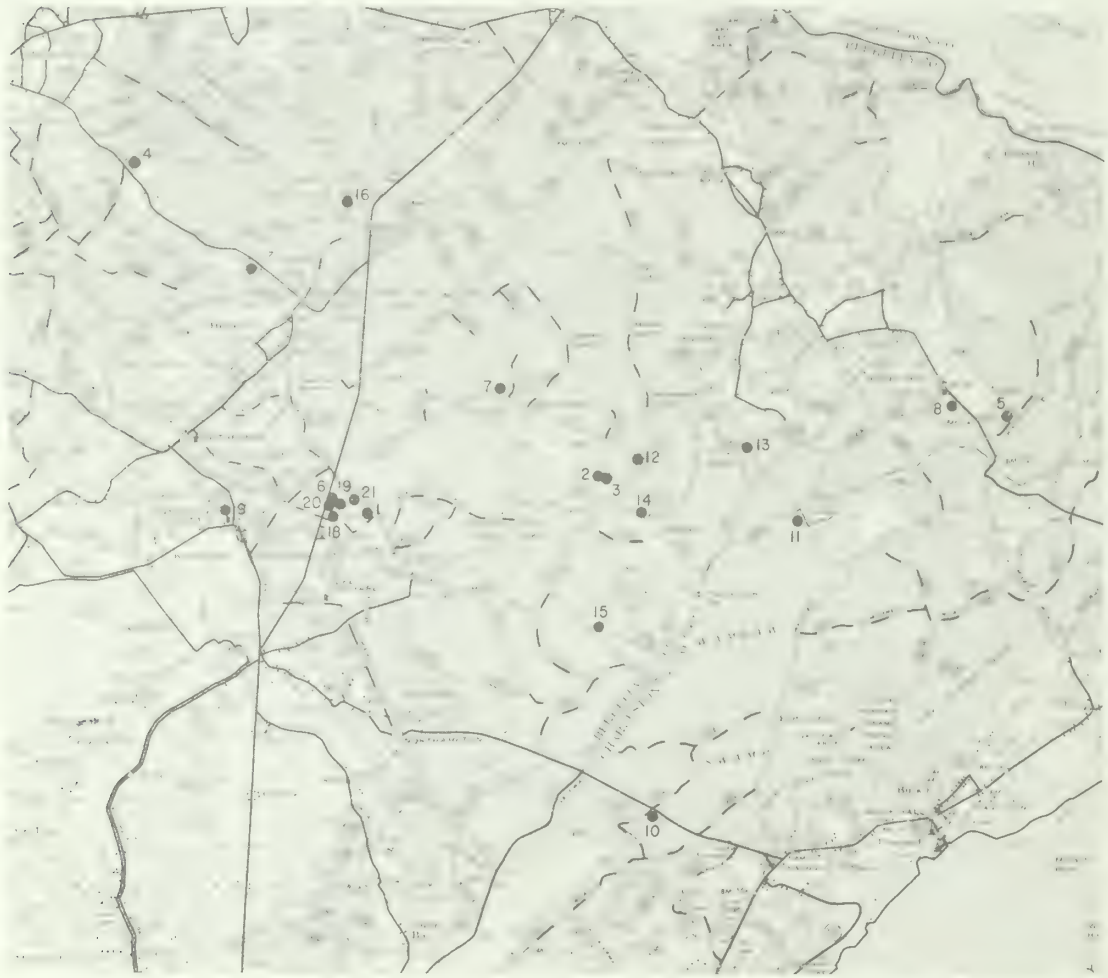

Figure 1.--Soil pit locations shown by respective numbers.

The soil pits were originally dug by Forest Service soil scientists to obtain profile descriptions. Thus, pits, profile descriptions, and a map showing pit locations were available for our study. Bobby Long, Soil Scientist, USDA Soil Conservation Service, reclassified certain soils to make the classification consistent with that for his recently completed soil survey of Berkeley and Charleston Counties, S. C. Consequently, many of the profiles do not represent modal characteristics of the soil type.

Field

Pits were enlarged or deepened to collect bulk soil samples and undisturbed soil cores. A bulk sample weighing approximately 1 pound was collected from each soil horizon and placed in a plastic bag. Duplicate undisturbed soil cores (7.60 cm in diameter and 5.51 cm long) were collected from each horizon using an enlarged version of a Lutz type soil sampler (Hoover, Metz, and Olson 1954), which extracts a soil core within a cylinder. A dull hacksaw blade was used to trim soil cores, and lids were then placed on top and bottom of the cylinders.

Laboratory

Soon after collection, the undisturbed soil cores were prepared for saturation. The bulk soil samples were spread on paper, air dried, crushed, and passed through a 2 mm sieve. Then moisture retention was determined at tensions of 1/3, 1, and 15 bars (1 bar approximately equals 1 atmosphere; 1 atmosphere = the pressure exerted by a water column or head 1,034 cm in height = a pressure of 14.7 pounds per square inch).

The procedure followed in determining 1/3-, 1-, and 15-bar tension was described by U. S. Salinity Laboratory Staff (Allison and others 1954). Moisture retention at 1/3- and 1-bar tension was measured on a pressure-plate apparatus. Duplicate 25-gram samples of soil were placed in the retainer rings on the ceramic porous pressure plates and saturated with water; then the plates were placed in the pressure cooker, the lid was sealed, and either 1/3- or 1-bar tension was applied. After the samples reached equilibrium moisture, pressure was released and samples were removed immediately and weighed; and then samples were dried at 105° C. and weighed. Moisture content at 1/3 and 1 bar was expressed as percent of ovendry weight. A pressure-membrane apparatus was used in determining moisture at 15 bars, and the procedure was similar to above for 1/3 and 1 bar.

Properties of undisturbed soil cores were determined by the procedure of Hoover and others (1954). The steps in saturating samples were: (1) attach cheese cloth on bottoms of cores, (2) place samples in a tub, (3) add one-half inch of water, and (4) gradually raise water in the tub each day until the samples were saturated. In some of the clayey soil samples, saturation required as long a 1 week. The saturated core samples were weighed and placed on a tension table at 60 cm tension (1/17.2 bar), and after equilibrium moisture was attained samples were weighed. Then the samples were ovendried at 105° C. and weighed to determine bulk density.

The storage capacity of soils for available moisture was estimated as the difference between moisture content at 60 cm and 15 bars. Although other researchers (Long and others 1963) have used moisture at a tension of 1/3 bar as an estimate of moisture at field capacity, we concurred with Lutz (1970) in setting the upper limit of available moisture between 50 and 100 cm tension. Steward and others (1963) arbitrarily set the upper limit of available water content at 0.10 bar for sandy-textured soils and 0.50 bar for finer textured soils.

RESULTS AND DISCUSSION

Soil profile descriptions and the physical and moisture characteristics for the 21 soil pits are presented in the Appendix by the alphabetical

order of soil series. The data include depth of horizon, bulk density, saturated porosity, percent moisture by volume at various tensions, and available moisture by horizons. Each value represents an average of duplicate samples, and there was good agreement between all replicate samples.

Bulk Density

Bulk density indirectly affects soil moisture characteristics--bulk density varies inversely with total porosity. In undisturbed forest soils, bulk density is lowest near the surface where organic matter content and activity of soil fauna are high. Bulk density is usually highest in the B horizon.

Saturated Porosity and Moisture at Various Tensions

The total porosity of a soil, on a percent by volume basis, represents the total water capacity at saturation. Theoretically, the moisture retained by a soil decreases progressively as water tension increases. We therefore were concerned that the moisture percentage at 1/3 bar sometimes exceeded the value at 60 cm tension and, in some cases, even exceeded the value extimated for saturated soil (see Appendix). We questioned whether the undisturbed cores used for the 60-cm and saturated determinations had been properly saturated. As a check on values for saturation porosity, we estimated the total porosity with the formula:

$$\text{Percent total porosity} = 100 - \left[\frac{(\text{Bulk density} \times 100)}{2.65}\right]$$

Total porosity estimated with this formula closely approximated observed saturated porosity, thereby indicating that the undisturbed soil cores were properly saturated. Unexpected differences in moisture values were probably due to variability of samples and to the methods involved--saturated porosity and moisture at 60 cm tension were determined in undisturbed soil cores, whereas moisture at 1/3 bar was applied to soil material passing through 2 mm sieve.

Moisture held at a constant tension is largely dependent upon soil texture and organic matter content. Moisture retention values at 1/3-, 1-, and 15-bar tension were usually lower for the A horizon than for the B horizons in individual profiles.

Storage Capacity of Soils for Available Moisture

The capacity of a soil to store available moisture was determined as the amount of water held between 60 cm (approximate field capacity) and 15 bars (approximate permanent wilting point) of tension. The moisture values in the Appendix tables are expressed in percent moisture by volume. Available moisture per inch is therefore the difference in moisture between tensions of 60 cm and 15 bars, divided by 100.

Since Coastal Plain soils are usually at or above field capacity at the beginning of spring, available moisture storage is a useful indicator of the droughty nature of soils. Depth of water table is another important determinant of water supply to trees because the water table of certain soils is at or near the soil surface at the beginning of the growing season and is

within the rooting zone periodically during the growing season, depending upon the amount and distribution of rainfall. Although shallow-rooted trees depend upon moisture stored near the soil surface, deep-rooted trees can absorb moisture stored at considerable depths during dry periods.

The storage capacity for available moisture is also useful for estimating the amount of rainfall or irrigation needed to bring the individual soils back to field capacity. Only in extreme droughts would soil moisture approach the permanent wilting point, so the amount of water needed to attain field capacity would normally be less than the amount calculated.

The texture of the A and B horizons affects soil moisture characteristics; fine material holds greater moisture than coarse particles, and soil organic matter also increases water storage by adding to surface areas of particles. In the B horizon of well developed soils there is a greater amount of clay than in the A horizon. For a given soil series, the texture of the B horizon, which is a series characteristic, varies less than the texture of the A horizon.

Table 1 gives the available moisture storage of the 21 soil profiles for depths to 36 inches. Available storage averages slightly less than 3½ inches of water in the 0- to 12-inch depth and 2½ inches of water per foot from the 12- to 36-inch depths. It averages 8.48 inches in the top 36 inches of soil.

Some indication of the variability and, perhaps, validity of the data can be obtained by comparing the values for soils that are represented by two or more pits (table 1). The available moisture in inches of water to a depth of 36 inches for the four series represented by two pits each are: Bayboro clay loam, 9.36 and 9.41; Meggett loam, 7.50 and 7.66; Pickney sand 13.24 and Pickney loamy sand 12.51; and Santee loam 15.81 and Santee clay loam 7.14. Thus, good agreement was found in all but the two Santee pits. We suspect that the value for Santee clay loam is an underestimate because the moisture determined at 60 cm tension appears too low in comparison to moisture at 1/3 bar (see Appendix). The eight pits representing Bethera suggest that within this series, available moisture to the 36-inch depth is greater for profiles having finer textured A horizons--the average of two pits for Bethera fine sandy loam is 7.23, the average of five pits for Bethera loam is 7.87, and the value of the single pit for Bethera clay loam is 9.48 inches of available water.

Another way to judge the validity of our values as series characteristics is to compare them with the data of other researchers who reported values for the same soil series. From studies in North Carolina, Lutz (1970) reported the water-holding capacity of 4 of the 10 series that we studied. The water-holding capacities to a 36-inch depth for these four series as reported by Lutz (1970) and as we present in table 1 are, respectively: Bayboro, 7.60 versus 9.38; Caroline, 9.47 versus 5.43; Craven, 6.80 versus 4.62; and Rains, 6.55 versus 7.47. Thus, two of four values for individual soil series differ by more than 2 inches of available water to a 36-inch depth. Some reasons for the discrepancies between Lutz's and our data are: (1) Since the soil profiles of our pits may not reflect modal conditions, following the current soil series descriptions made by the Soil Conservation Service, the texture of the B horizon may not be typical for series. (2) Organic matter and texture of the A horizon may vary enough to cause large differences in water-holding capacity. (3) An unknown amount of error results from both the collection and analysis of soil samples.

Table 1.--Storage capacity for available moisture in the surface 3 feet of soil at 21 pit locations

Soil type	Pit No.	Available moisture by depth in profile				
		0-6"	6-12"	12-24"	24-36"	Total 0-36"
		Inches of water				
Bayboro clay loam	1	1.64	1.66	3.08	2.98	9.36
Bayboro clay loam	2	2.74	1.87	2.44	2.36	9.41
Bethera fine sandy loam	7	1.58	1.15	2.14	2.15	7.02
Bethera fine sandy loam	15	1.79	1.19	2.06	2.40	7.44
Bethera loam	3	2.29	1.23	2.34	2.05	7.91
Bethera loam	4	1.72	.99	1.42	1.42	5.55
Bethera loam	5	1.85	1.41	2.58	3.02	8.86
Bethera loam	6	1.99	1.57	2.60	2.47	8.63
Bethera loam	12	2.25	1.41	2.44	2.29	8.39
Bethera clay loam	19	2.59	1.81	2.97	2.11	9.48
Caroline fine sandy loam	20	1.47	1.27	1.56	1.13	5.43
Craven loam	18	1.16	.71	1.55	1.20	4.62
Meggett loam	8	1.68	1.09	2.32	2.41	7.50
Meggett loam	9	1.91	1.31	2.34	2.10	7.66
Pantego loam	13	2.18	1.47	2.13	2.68	8.46
Pickney sand	16	3.00	2.05	3.40	4.79	13.24
Pickney loamy sand	17	2.23	2.24	4.18	3.86	12.51
Rains fine sandy loam	14	1.64	1.37	2.07	2.39	7.47
Santee loam	11	3.65	3.10	5.10	3.96	15.81
Santee clay loam	10	1.27	1.14	2.13	2.60	7.14
Wahee loam	21	1.40	.91	1.89	1.93	6.13
Average		2.00	1.47	2.51	2.49	8.48

We conclude that our data on the 10 soils series are sufficient for rough estimates of available moisture-holding capacity in the Lower Coastal Plain of South Carolina. Where precise estimates of available soil moisture are needed on certain areas, such as small watersheds or research study plots, we recommend that soil samples be taken. The soil moisture-holding capacity and other important physical properties can then be determined from tests made in a suitable soils laboratory.

APPENDIX

BAYBORO SERIES

Soil Type: Bayboro clay loam Pit No.: 1
Classification: Umbric Paleaquults--clayey, mixed thermic
Drainage: Very poorly drained
Relief: Nearly level to slightly depressional, saucerlike areas or drainageways.

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	Percent by volume					Inch	Inches
A11	0-10	0.97	61.8	52.9	41.3	34.6	25.5	0.274	2.74
A12	10-14	1.07	58.5	54.6	43.2	36.6	26.4	.282	3.87
B21tg	14-17	1.11	57.5	54.3	45.0	38.5	27.1	.272	4.68
B22tg	17-29	1.18	56.3	53.7	49.3	40.9	29.4	.243	7.60
B23tg	29-36	1.18	56.1	54.2	48.9	41.8	29.1	.251	9.36
B24tg	36-62	1.14	59.4	57.4	49.7	41.4	29.1	.283	16.72

Horizon	Depth Inches	Horizon description
A11	0-10	Black (10YR 2/1) clay loam; weak fine granular structure; friable; very strongly acid; clear smooth boundary.
A12	10-14	Very dark gray (10YR 3/1) clay loam; common fine faint dark yellowish brown mottles; weak fine granular structure; friable; very strongly acid; clear smooth boundary
B21tg	14-17	Dark gray (10YR 4/1) clay; few fine distinct yellowish brown mottles; weak fine subangular blocky structure; firm; thin patchy faint clay films on faces of peds; very strongly acid; abrupt smooth boundary.
B22tg	17-29	Dark gray (10YR 4/1) clay; many medium distinct brownish yellow (10YR 6/6) and strong brown (7.5YR 5/6) mottles; moderate medium subangular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few fine pores; very strongly acid; clear wavy boundary.
B23tg	29-36	Gray (10YR 5/1) clay; common fine and medium faint dark yellowish brown (10YR 4/4) and brownish yellow (10YR 6/6) mottles; moderate medium subangular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few fine and medium pores; very strongly acid; clear wavy boundary.

B24tg	36-62	Gray (10YR 5/1) clay; many coarse faint yellowish brown (10YR 5/6) mottles; weak medium subangular blocky structure; firm; sticky, plastic; patchy distinct clay films on faces of peds; very strongly acid; clear wavy boundary.
Cg	62-72	Gray (10YR 5/1) clay; many coarse faint yellowish brown (10YR 5/6) and dark yellowish brown (10YR 3/4) mottles; massive; firm; sticky, plastic; strongly acid.

Location: Berkeley County photo 3T-72. 0.13 mile NW of Lotti Road on Conifer Road and 50 feet SW of Conifer Road.

Soil Type: Bayboro clay loam Pit No.: 2
Classification: Umbric Paleaquults--clayey, mixed, thermic
Drainage: Very poorly drained
Relief: Nearly level to slightly depressional, saucerlike areas or drainageways

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - Percent by volume - - - - - - -					Inch	Inches
A11	0-6	0.50	76.4	63.4	37.7	30.9	17.7	0.457	2.74
A12	6-9	0.74	66.7	56.8	37.6	30.5	21.3	.355	3.81
B21tg	9-12	1.08	56.1	53.0	43.1	34.3	26.1	.269	4.61
B22tg	12-28	1.36	47.9	45.1	44.8	33.1	24.8	.203	7.86
B23tg	28-54	1.34	49.4	47.0	48.0	36.4	27.6	.194	12.91
B3g	54-60	1.32	51.5	50.4	51.3	40.1	28.6	.218	14.21

Horizon	Depth Inches	Horizon description
A11	0-6	Black (10YR 2/1) clay loam; weak fine granular structure; friable, slightly sticky, slightly plastic; very strongly acid; clear wavy boundary.
A12	6-9	Black (N2/) clay loam; weak fine granular structure; friable, slightly sticky, slightly plastic; very strongly acid; abrupt wavy boundary.
B21tg	9-12	Very dark gray (10YR 3/1) clay; few fine faint dark yellowish brown mottles; weak fine subangular blocky structure; firm; slightly sticky, plastic; thin patchy faint clay films on faces of peds; common fine pores; very strongly acid; clear wavy boundary.
B22tg	12-28	Dark gray (10YR 4/1) clay; common medium distinct strong brown (7.5YR 5/6) and few fine faint dark yellowish brown mottles; moderate medium subangular blocky structure; firm; slightly sticky, plastic; broken distinct clay films on faces of peds; common fine pores; very strongly acid; gradual wavy boundary.
B23tg	28-54	Gray (10YR 5/1) clay; many coarse distinct strong brown (7.5YR 5/8) and common medium distinct yellowish red (5YR 4/6) reddish brown (5YR 4/3) and dark reddish brown (5YR 3/3) mottles; firm; sticky, plastic; moderate medium subangular blocky structure; broken distinct clay films on faces of peds; very strongly acid; gradual wavy boundary.

B3g	54-60	Mottled dark gray (10YR 4/1), gray (10YR 6/1), light gray (5Y 7/1), yellow (2.5Y 7/6), yellowish red (5YR 4/6), strong brown (7.5YR 5/6) and dark reddish brown (5YR 3/3) clay; weak fine subangular blocky structure; firm; slightly sticky, plastic; very strongly acid.

Location: Berkeley County photo 2T-158. Approximately 0.7 mile NW of intersection of Conifer A and B Roads on Conifer A Road and 35 feet S of road.

BETHERA SERIES

Soil Type: Bethera fine sandy loam Pit No.: 7
Classification: Typic Paleaquults-clayey, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level flats or slightly depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	Percent by volume					Inch	Inches
A1	0-3	1.20	54.0	44.2	22.6	16.1	11.8	0.324	0.97
A2	3-6	1.55	37.8	31.2	23.4	17.5	10.8	.204	1.58
B1g	6-15	1.59	40.8	36.4	31.6	25.5	17.3	.191	3.30
B21tg	15-34	1.57	41.8	38.9	38.8	31.6	21.5	.174	6.61
B22tg	34-49	1.50	46.4	42.8	36.9	31.4	22.2	.206	9.70
B23tg	49-60	1.59	42.7	39.2	30.8	24.6	15.4	.238	12.32

Horizon	Depth Inches	Horizon description
A1	0-3	Black (10YR 2/1) fine sandy loam; weak fine granular structure; very friable; strongly acid; abrupt wavy boundary.
A2	3-6	Dark gray (10YR 4/1) fine sandy loam; weak medium subangular blocky structure; very friable; strongly acid; abrupt wavy boundary.
B1g	6-15	Light brownish gray (10YR 6/2) sandy clay loam; few fine distinct brownish yellow mottles; weak coarse prismatic breaking to weak coarse subangular blocky structure; friable, slightly sticky, slightly plastic; many fine pores; strongly acid; gradual wavy boundary.
B21tg	15-34	Gray (10YR 6/1) clay; many medium distinct brownish yellow (10YR 6/6) and red (2.5YR 4/6) mottles; strong coarse subangular and angular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few fine pores; strongly acid; gradual wavy boundary.
B22tg	34-49	Gray (10YR 6/1) sandy clay; common coarse distinct brownish yellow (10YR 6/8) mottles; moderate medium prismatic breaking to medium subangular and angular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few fine pores; strongly acid; gradual irregular boundary.

B23tg	49-60	Gray (10YR 6/1) sandy clay; common coarse distinct olive yellow (2.5Y 6/6) mottles; moderate medium subangular blocky structure; firm; slightly sticky, slightly plastic; patchy distinct clay films on faces of peds; few fine pores; strongly acid.

Location: Berkeley County photo 8T-60. Yellowjacket Road, 0.2 mile W to NW of Farewell Corner Road and 50 feet N of Yellowjacket Road.

Soil Type: Bethera fine sandy loam Pit No.: 15
Classification: Typic Paleaquults--clayey, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level flats or slightly depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	Percent by volume					Inch	Inches
A1	0-7	1.31	46.7	37.2	16.8	12.3	7.4	0.298	2.09
A2	7-12	1.42	43.6	36.8	29.7	26.0	18.9	.179	2.98
B1g	12-16	1.62	38.7	36.3	34.1	28.0	20.6	.157	3.61
B21tg	16-21	1.66	37.7	35.9	33.5	27.1	19.2	.167	4.44
B22tg	21-42	1.62	39.6	37.5	30.6	25.7	17.5	.200	8.64
B23tg	42-56	1.70	36.7	34.9	28.9	23.9	17.2	.177	11.12
B3g	56-70	1.67	37.2	31.7	18.1	14.8	10.1	.216	14.15
C1g	70-76	1.62	38.5	27.8	12.9	10.2	6.6	.212	15.42
C2g	76-85	1.62	40.7	33.6	14.3	11.2	7.6	.260	17.76

Horizon	Depth Inches	Horizon description
A1	0-7	Black (10YR 2/1) fine sandy loam; weak fine granular structure; friable; very strongly acid; clear wavy boundary.
A2	7-12	Grayish brown (2.5Y 5/2) fine sandy loam; few fine faint pale brown and dark gray mottles; weak fine granular structure; friable; very strongly acid; clear wavy boundary.
B1g	12-16	Grayish brown (2.5Y 5/2) sandy clay loam; common fine distinct yellowish brown and gray mottles; weak fine subangular blocky structure; friable; few fine pores; very strongly acid; clear irregular boundary.
B21tg	16-21	Gray (10YR 6/1) sandy clay; common medium distinct yellowish brown (10YR 5/6) and light olive brown (2.5Y 5/4) mottles; moderate medium subangular blocky structure; firm; slightly plastic; broken distinct clay films on faces of peds; few fine pores; very strongly acid; clear wavy boundary.

B22tg	21-42	Gray (10YR 6/1) sandy clay; common medium distinct brownish yellow (10YR 6/6), yellowish brown (10YR 5/6) and few fine faint yellowish red and red mottles and very dark gray mottles in old root holes; moderate medium subangular blocky structure; firm; slightly sticky, slightly plastic; broken distinct clay films on faces of peds; few fine pores; very strongly acid; clear wavy boundary
B23tg	42-56	Gray (10YR 6/1) sandy clay; common fine distinct brownish yellow, gray and few medium prominent red (2.5YR 4/6) mottles; weak medium subangular blocky structure; friable; patchy distinct clay films on faces of peds; few pockets of sandy loam; few mica flakes; very strongly acid; gradual irregular boundary.
B3g	56-70	Light gray (5Y 6/1) sandy clay loam; common fine distinct olive brown and yellowish brown mottles; weak fine subangular blocky structure; very friable; few pockets of loamy sand, sand and sandy loam; few mica flakes; very strongly acid; clear smooth boundary.
C1g	70-76	Mottled light gray (5Y 7/1), pale yellow (2.5Y 7/4) and very pale brown (10YR 7/4) loamy sand; single grain; very friable to loose; many mica flakes; very strongly acid; clear smooth boundary.
C2g	76-85	Light gray (5Y 7/1) loamy sand; few fine faint light brownish gray, pale yellow and pale olive mottles; single grain; very friable; many mica flakes; strongly acid.

Location: Berkeley County photo 2T-156. Intersection of Farewell Corner Road and 48 feet NW of Brunson Road.

Soil Type: Bethera loam Pit No.: 3
Classification: Typic Paleaquults-clayey, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level flats or slightly depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - - Percent by volume - - - - - - - -					Inch	Inches
A1	0-5	0.78	66.0	56.8	36.6	28.0	15.6	0.412	2.06
A2	5-8	1.31	46.7	38.2	34.1	25.7	15.1	.231	2.75
B1g	8-12	1.53	41.8	36.9	36.7	29.2	17.8	.191	3.52
B21tg	12-33	1.49	43.8	41.3	41.4	32.8	21.8	.195	7.61
B22tg	33-46	1.54	42.1	40.3	51.2	43.0	30.4	.099	8.90
B23tg	46-60	1.36	50.6	49.3	46.1	38.1	26.0	.233	12.16
B3g	60-72	1.59	41.3	40.2	31.3	25.9	16.1	.241	15.05

Horizon	Depth Inches	Horizon description
A1	0-5	Very dark gray (10YR 3/1) loam; weak fine granular structure; friable; strongly acid; abrupt wavy boundary.
A2	5-8	Gray (10YR 5/1) loam; few fine faint very dark gray, few fine distinct dark yellowish brown and yellowish brown mottles; weak fine granular structure; friable; very strongly acid; abrupt wavy boundary.
B1g	8-12	Gray (10YR 5/1) clay loam; common fine distinct yellowish brown mottles; weak fine subangular blocky structure; friable, slightly sticky, plastic; strongly acid; clear wavy boundary.
B21tg	12-33	Gray (10YR 5/1) clay; many coarse distinct strong brown (7.5YR 5/8) and common fine distinct reddish yellow mottles; weak coarse prismatic breaking to moderate fine and medium subangular blocky structure; firm; slightly sticky, plastic; broken distinct continuous clay films on faces of peds; few fine pores; very strongly acid; gradual wavy boundary.
B22tg	33-46	Dark gray (10YR 4/1) clay; many coarse distinct yellow (10YR 7/8), strong brown (7.5YR 5/6) and common fine faint yellowish red and dark yellowish brown mottles; moderate fine subangular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few fine pores; very strongly acid; gradual wavy boundary.

B23tg	46-60	Gray (5Y 6/1) clay; many coarse distinct gray (10YR 5/1), yellow (10YR 7/8) and common fine faint yellowish red mottles; weak fine subangular blocky structure; firm; sticky, plastic; thin patchy faint clay films on faces of peds; very strongly acid; gradual irregular boundary.
B3g	60-72	Gray (10YR 5/1) and light gray (5Y 7/1) sandy clay; few fine distinct olive brown, yellowish brown and greenish gray mottles; weak fine subangular blocky structure; friable, slightly plastic; contains coarse lenses or pockets of sandy loam; very strongly acid.

Location: Berkeley County photo 2T-158. Approximately 0.6 mile NW of intersection of Conifer A and B Roads on Conifer A Road and 30 feet SW of road.

Soil Type: Bethera loam Pit No.: 4
Classification: Typic Paleaquults--clayey, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level flats or slightly depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	Percent by volume					Inch	Inches
A11	0-2	1.04	58.4	51.5	34.1	26.5	16.8	0.347	0.69
A12	2-4	1.31	46.9	39.4	32.4	24.0	12.5	.269	1.23
A2	4-7	1.43	43.4	37.6	31.4	23.5	13.0	.246	1.97
B21tg	7-10	1.61	39.6	36.1	36.1	29.5	19.3	.168	2.47
B22tg	10-41	1.58	41.0	38.6	44.2	37.7	26.8	.118	6.13
B23tg	41-68	1.51	45.3	43.4	48.1	39.7	29.5	.139	9.88
C1g	68-94	1.39	55.4	53.0	61.7	50.4	32.9	.201	15.11

Horizon	Depth Inches	Horizon description
A11	0-2	Very dark gray (10YR 3/1) loam; moderate fine granular structure; friable; many fine and medium roots; extremely acid; abrupt wavy boundary.
A12	2-4	Dark gray (10YR 4/1) loam; weak fine granular structure; friable; many fine and medium roots; extremely acid; abrupt wavy boundary.
A2	4-7	Gray (10YR 5/1) loam; weak fine granular structure; friable; many fine roots; many fine pores; very strongly acid; abrupt wavy boundary.
B21tg	7-10	Grayish brown (10YR 5/2) clay loam; few fine faint gray and common fine distinct brownish yellow mottles; weak fine angular blocky structure; firm; sticky, plastic; patchy faint clay films on faces of peds; few fine roots; few fine pores; very strongly acid; abrupt wavy boundary.
B22tg	10-41	Gray (10YR 5/1) clay; common medium distinct brownish yellow (10YR 6/6) and common medium prominent red (10R 4/6) mottles; moderate fine angular blocky structure; firm; sticky, plastic; patchy distinct clay films on faces of peds; few fine roots; few fine pores; very strongly acid; gradual wavy boundary.

B23tg	41-68	Gray (10YR 5/1) clay; many medium distinct brownish yellow (10YR 6/8) mottles; moderate fine angular blocky structure; firm; sticky, plastic; patchy distinct clay films on faces of peds; very strongly acid; gradual wavy boundary.
C1g	68-94	Mottled light brownish gray (2.5Y 6/2), gray (5Y 6/1), and light gray (10YR 7/1) clay; massive; firm; sticky, plastic; extremely acid; clear smooth boundary.
C2g	94-97	Greenish gray (5BG 5/1) clay; massive; firm; sticky, plastic; very strongly acid.

Location: Berkeley County, South Carolina; 13 miles NE of Moncks Corner; from Macedonia travel southeast on South Carolina secondary Highway 48 for 3.7 miles; site is 100 feet NE of highway.

Soil Type: Bethera loam Pit No.: 5
Classification: Typic Paleaquults--clayey, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level flats or slightly depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - - Percent by volume - - - - - - - -					Inch	Inches
A1	0-3	0.93	66.5	51.7	38.6	26.3	15.3	0.364	1.09
B21tg	3-9	1.39	46.9	42.8	46.0	30.3	17.4	.254	2.62
B22tg	9-24	1.46	46.6	44.4	49.9	38.0	22.9	.215	5.84
B23tg	24-60	1.32	51.4	48.6	47.0	36.4	23.4	.252	14.91

Horizon	Depth Inches	Horizon description
A1	0-3	Very dark gray (10YR 3/1) loam; weak fine granular structure; friable, slightly plastic; very strongly acid; abrupt wavy boundary.
B21tg	3-9	Light brownish gray (10YR 6/2) clay loam; many medium distinct yellowish brown (10YR 5/6) and strong brown (7.5YR 5/6) mottles; weak fine subangular blocky structure; firm; slightly sticky, plastic; patchy faint clay films on faces of peds; few fine roots; few fine pores; very strongly acid; clear wavy boundary.
B22tg	9-24	Gray (10YR 6/1) clay; many medium distinct brownish yellow (10YR 6/6) mottles; weak coarse prismatic breaking to moderate medium subangular blocky structure; firm; sticky, plastic; broken faint clay films on faces of peds; few fine roots; few fine pores; very strongly acid; gradual wavy boundary.
B23tg	24-60	Gray (5Y 6/1) clay; many coarse prominent yellowish red (5YR 5/6) and common medium distinct strong brown (7.5YR 5/6) mottles and dark gray mottles in old root channels; moderate medium angular blocky structure; firm; sticky, plastic; broken faint clay films on faces of peds; very strongly acid.

Location: Berkeley County photo 2T-34. Approximately 1 mile N of S. C. #45 on Wardfield Road, about 100 feet W of road.

Soil Type: Bethera loam Pit No.: 6
Classification: Typic Paleaquults--clayey, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level flats or slightly depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - Percent by volume - - - - - - -					Inch	Inches
A1	0-4	1.09	55.8	49.7	32.4	24.3	14.1	0.356	1.42
A2	4-8	1.37	46.8	44.2	34.5	26.9	15.9	.283	2.56
B21tg	8-12	1.50	42.9	40.6	33.4	25.9	15.4	.252	3.56
B22tg	12-23	1.45	44.6	42.7	36.8	31.0	20.9	.218	5.96
B23tg	23-37	1.55	43.1	41.3	35.3	30.2	20.7	.206	8.85
B24tg	37-52	1.56	42.9	41.2	41.5	35.6	24.4	.168	11.37
B3g	56-61	1.71	39.4	37.7	41.2	32.4	21.0	.167	12.87

Horizon	Depth Inches	Horizon description
A1	0-4	Very dark gray (10YR 3/1) loam; weak fine granular structure; friable; very strongly acid; clear smooth boundary.
A2	4-8	Dark gray (10YR 4/1) loam; common fine distinct brown and yellowish brown mottles; weak fine granular structure; very strongly acid; clear smooth boundary.
B21tg	8-12	Gray (10YR 5/1) clay loam; common fine distinct yellowish brown mottles; weak fine subangular blocky structure; friable, slightly plastic; patchy faint clay films on faces of peds; common fine and medium pores; very strongly acid; gradual wavy boundary.
B22tg	12-23	Gray (10YR 5/1) clay; common medium distinct strong brown (7.5YR 5/6) and yellowish brown (10YR 5/6) mottles; firm; broken distinct clay films on faces of peds; common fine and medium pores; very strongly acid; clear wavy boundary.
B23tg	23-37	Gray (10YR 5/1) clay; many medium distinct brownish yellow (10YR 6/6) and red (2.5YR 4/6) mottles; moderate medium subangular blocky structure; firm;broken distinct clay films on faces of peds; common fine and medium pores; few fine black concretions; extremely acid; gradual smooth boundary.

B24tg	37-52	Gray (10YR 5/1) clay; many medium distinct brownish yellow (10YR 6/6), red (2.5YR 4/6) and dark red (2.5YR 3/6) mottles; moderate medium subangular blocky structure; firm; patchy faint clay films on faces of peds; few fine black concretions; few fine pores; very strongly acid; gradual wavy boundary.
B3g	52-61	Gray (10YR 5/1) sandy clay; many coarse distinct brownish yellow (10YR 6/6) and red (2.5YR 4/6) mottles; weak fine subangular blocky structure; firm; strongly acid.

Location: Berkeley County photo 3T-70. Santee Experimental Forest Watershed Study Unit. 100 feet N of weir and 30 feet E of S. C. Highway 41.

Soil Type: Bethera loam Pit No.: 12
Classification: Typic Paleaquults--clayey, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level flats or slightly depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	Percent by volume					Inch	Inches
A11	0-5	0.95	59.6	53.1	32.2	23.5	13.2	0.399	2.00
A12	5-9	1.30	47.6	40.2	30.5	22.3	14.8	.254	3.01
B21tg	9-18	1.49	41.6	38.1	32.2	25.3	16.5	.216	4.96
B22tg	18-36	1.56	41.0	38.2	37.9	29.4	19.1	.191	8.39
B23tg	36-48	1.51	44.1	42.0	37.5	29.0	18.7	.233	11.19
B24tg	48-54	1.41	48.3	46.4	46.7	37.6	25.2	.212	12.46

Horizon	Depth Inches	Horizon description
A11	0-5	Black (10YR 2/1) loam; weak fine granular structure; friable; very strongly acid; abrupt wavy boundary.
A12	5-9	Very dark gray (10YR 3/1) loam; few fine faint dark brown mottles in old root channels; weak fine granular structure; friable; common fine pores; very strongly acid; clear wavy boundary.
B21tg	9-18	Dark gray (10YR 4/1) clay loam; common fine faint dark yellowish brown mottles and few fine faint dark brown mottles around old root channels; weak fine subangular blocky structure; firm; slightly sticky, plastic; patchy distinct clay films on faces of peds; common fine pores; very strongly acid; clear wavy boundary.
B22tg	18-36	Gray (10YR 5/1) clay loam; common medium faint dark yellowish brown (10YR 4/4) and common medium prominent yellowish red (5YR 4/6) mottles, the latter is mainly in old root channels and worm holes; moderate fine subangular blocky structure; firm; slightly sticky, slightly plastic; broken distinct continuous clay films on faces of peds; common fine pores, very strongly acid; gradual wavy boundary.
B23tg	36-48	Gray (10YR 5/1) clay loam; common fine distinct reddish brown, yellowish red and strong brown mottles; weak fine subangular blocky structure; firm; slightly sticky, plastic; few fine pores; very strongly acid; gradual wavy boundary.

B24tg	48-54	Gray (10YR 5/1) clay; many coarse distinct brownish yellow (10YR 6/6), dark yellowish brown (10YR 4/4), yellow (2.5Y 7/6) and reddish brown (5YR 4/4) mottles; weak medium subangular blocky structure; firm; slightly sticky plastic; patchy faint clay films on faces of peds; very strongly acid; gradual wavy boundary.
B25tg	54-60	Gray (N5/) clay; many coarse distinct brownish yellow (10YR 6/6), dark yellowish brown (10YR 4/4), yellow (2.5Y 7/6), and reddish brown (5YR 4/3) mottles; weak medium subangular blocky structure; firm; slightly sticky, plastic; patchy faint clay films on faces of peds; very strongly acid.

Location: Berkeley County photo 2T-158. Conifer B Road, 0.25 mile N of Conifer A and Conifer B intersection at superior tree FRA 68.

Soil Type: Bethera clay loam Pit No.: 19
Classification: Typic Paleaquults--clayey, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level flats or slightly depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - - Percent by volume - - - - - - - -					Inch	Inches
A11	0-5	0.91	66.9	57.9	32.0	24.2	12.2	0.457	2.28
A12	5-15	1.36	50.0	46.3	36.8	29.4	16.1	.302	5.30
B21tg	15-19	1.41	48.5	45.9	38.5	29.5	16.7	.292	6.47
B22tg	19-34	1.46	46.7	44.8	48.4	40.8	26.9	.179	9.16
B23tg	34-52	1.57	43.2	42.0	46.7	39.5	26.0	.160	12.04

Horizon	Depth Inches	Horizon description
A11	0-5	Dark gray (10YR 4/1) clay loam; weak fine granular structure; friable, many fine and medium roots; very strongly acid; abrupt smooth boundary.
A12	5-15	Dark gray (10YR 4/1) clay loam; common fine faint mottles of gray and organic stains in old root channels; weak fine granular structure; friable; many fine and medium roots; very strongly acid; abrupt wavy boundary.
B21tg	15-19	Gray (10YR 5/1) clay; common fine distinct dark yellowish brown and dark brown mottles; weak fine subangular blocky structure; friable; patchy faint clay films on faces of peds; common fine medium and large roots; common fine and medium pores; very strongly acid; clear smooth boundary.
B22tg	19-34	Gray (10YR 5/1) clay; many medium distinct strong brown (7.5YR 5/6) and dark yellowish brown (10YR 4/4) mottles; moderate medium subangular blocky structure; firm; complete distinct clay films on faces of peds; common fine medium and large roots; common fine and medium pores; very strongly acid; gradual wavy boundary.
B23tg	34-52	Gray (10YR 5/1) clay; few medium distinct brownish yellow (10YR 6/6), dark yellowish brown (10YR 4/4) and dark brown (7.5YR 4/4) mottles; weak fine subangular blocky structure; firm; broken faint clay films on faces of peds; few fine roots; few fine and medium pores; very strongly acid; gradual smooth boundary.

B24tg	52-68	Light gray (N6/) clay; common medium distinct brownish yellow (10YR 6/6) and brown (10YR 5/3) mottles; weak fine subangular blocky structure; firm; patchy faint clay films on faces of peds; few fine roots; strongly acid; gradual smooth boundary.

Location: Berkeley County photo 3T-70. Santee Experimental Forest Watershed Study Unit. 500 feet E of weir near upper end of ponding basin.

Soil Type: Caroline fine sandy loam Pit No.: 20
Classification: Typic Hapludults--clayey, mixed, thermic
Drainage: Well drained
Relief: Level to gently sloping, rolling uplands or stream terraces.

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - - Percent by volume - - - - - - - -					Inch	Inches
A1	0-3	1.33	46.1	32.9	23.0	17.2	9.5	0.234	0.70
A2	3-9	1.35	44.3	33.3	26.1	17.2	7.8	.255	2.23
B21t	9-15	1.57	41.0	31.8	31.4	24.5	15.1	.167	3.23
B22t	15-19	1.70	38.1	30.6	30.1	26.0	19.5	.111	3.68
B23t	19-31	1.77	34.9	27.8	25.8	21.6	15.4	.124	5.17
B3	31-50	1.84	29.4	20.8	26.0	21.9	15.5	.053	6.17
Cg	50-72	1.83	31.5	26.4	33.0	23.6	19.5	.069	7.69

Horizon	Depth Inches	Horizon description
A1	0-3	Dark grayish brown (10YR 4/2) fine sandy loam; weak fine granular structure; very friable; many fine and medium roots; strongly acid; abrupt smooth boundary.
A2	3-9	Light yellowish brown (10YR 6/4) fine sandy loam; weak fine granular structure; very friable; many fine medium and large roots; strongly acid; gradual smooth boundary.
B21t	9-15	Yellowish red (5YR 4/8) clay loam; few fine faint red and strong brown mottles; moderate fine subangular blocky structure; firm; broken distinct clay films on faces of peds; common fine and medium roots; common fine and medium pores; very strongly acid; clear smooth boundary.
B22t	15-19	Reddish yellow (7.5YR 6/6) sandy clay; many fine and medium distinct red (2.5YR 4/6) and light yellowish brown (10YR 6/4) mottles; many quartz crystals between 2 and 5 millimeters in size; moderate fine subangular blocky structure; firm; broken distinct clay films on faces of peds; few fine medium and large roots; common fine and medium pores; very strongly acid; gradual smooth boundary.

B23t	19-31	Reddish yellow (7.5YR 6/6) sandy clay; many fine distinct red and strong brown mottles; weak fine subangular blocky structure; firm; many small quartz crystals; patchy faint clay films on faces of peds; few fine and medium roots; few fine pores; very strongly acid; gradual wavy boundary.
B3	31-50	Strong brown (7.5YR 5/8) sandy clay loam; few fine distinct gray and red mottles; many quartz crystals; weak fine subangular blocky structure; very strongly acid; gradual wavy boundary.
Cg	50-72	Gray (2.5Y 6/) and dark red (10R 3/6) sandy clay loam; few fine distinct strong brown and yellowish brown mottles; many quartz crystals; massive; very strongly acid.

Location: Berkeley County photo 3T-72. Santee Experimental Forest Watershed Study Unit. 200 yards S of weir and 40 feet E of Highway 41.

Soil Type: Craven loam Pit No.: 18
Classification: Aquic Hapludults--clayey, mixed, thermic
Drainage: Moderately well drained
Relief: Nearly level to gently sloping ridgetops or breaks

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - - Percent by volume - - - - - - - -					Inch	Inches
A1	0-2	1.35	44.8	36.6	31.7	20.4	9.0	0.276	0.55
A2	2-7	1.74	32.7	29.3	35.9	27.0	14.0	.153	1.32
B21t	7-11	1.57	42.0	40.3	50.0	42.3	29.8	.105	1.74
B22t	11-18	1.39	47.7	44.5	48.3	42.3	30.7	.138	2.70
B23t	18-28	1.35	48.5	44.7	50.8	44.6	32.6	.121	3.91
B24t	28-38	1.46	45.9	44.1	53.9	48.1	35.2	.089	4.80
B3g	38-55	1.55	43.3	41.3	39.4	34.8	24.1	.172	7.73
C1g	55-66	1.53	45.4	43.2	39.9	34.8	24.5	.187	9.78
C2g	66-78	1.58	44.6	42.2	43.1	36.3	26.2	.160	11.70

Horizon	Depth Inches	Horizon description
A1	0-2	Dark gray (10YR 4/1) loam; weak fine granular structure; very friable; many fine and medium roots; very strongly acid; abrupt smooth boundary.
A2	2-7	Pale brown (10YR 6/3) clay loam; weak fine granular structure; very friable; many fine, medium and large roots; very strongly acid; clear smooth boundary.
B21t	7-11	Light yellowish-brown (10YR 6/4) clay; few fine distinct yellowish-red mottles; moderate fine subangular blocky structure; friable; broken faint clay films on faces of peds; common fine, medium and large roots; few fine pores; very strongly acid; gradual smooth boundary.
B22t	11-18	Yellowish-brown (10YR 5/4) clay; common fine prominent red mottles; strong medium subangular blocky structure; firm; patchy faint clay films on faces of peds; few fine and medium roots; common fine and medium pores; occasional organic stains on peds and in pores; very strongly acid; gradual smooth boundary.

B23t	18-28	Pale brown (10YR 6/3) clay with few pockets of sand; common medium distinct strong brown (7.5YR 5/6), red (10R 4/6) and few fine faint gray mottles; moderate medium subangular blocky structure; firm; complete prominent clay films on faces of peds; few fine and medium roots; common fine pores; very strongly acid; abrupt wavy boundary.
B24t	28-38	Mottled grayish-brown (10YR 5/2), yellowish-brown (10YR 5/6) and red (2.5YR 4/6) clay; weak medium subangular blocky structure; firm; patchy faint clay films on faces of peds; few fine and medium roots; few fine pores; very strongly acid; gradual wavy boundary.
B3g	38-55	Grayish-brown (10YR 5/2) clay; few fine prominent dark red and brownish-yellow mottles; weak fine subangular blocky structure; firm; very strongly acid; gradual wavy boundary.
C1g	55-66	Gray (10YR 6/1) clay; common medium distinct yellowish brown (10YR 5/6) and dark red (10R 3/6) mottles; massive; firm; very strongly acid; diffuse wavy boundary.
C2g	66-78	Gray (10YR 6/1) clay; common medium distinct yellowish brown (10YR 5/6), brownish yellow (10YR 6/6) and common medium prominent red (2.5YR 4/6) mottles; massive; firm; very strongly acid.

Location: Berkeley County photo 3T-72. Santee Experimental Forest Watershed Study Unit. 100 yards E of Highway 41 on N edge of Lotti Road.

Soil Type: Meggett loam Pit No.: 8
Classification: Typic Albaqualfs--fine, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level, low-lying areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - - Percent by volume - - - - - - - -					Inch	Inches
A1	0-4	1.03	62.6	52.7	36.6	29.4	19.9	0.328	1.31
B21tg	4-16	1.52	44.5	42.7	44.3	36.7	24.5	.182	3.50
B22tg	16-33	1.46	48.3	46.3	47.7	38.7	26.4	.199	6.88
B23tg	33-42	1.50	48.1	45.9	46.5	37.2	25.4	.205	8.72
B24tg	42-60	1.36	57.3	54.5	57.0	45.7	29.8	.247	13.17

Horizon	Depth Inches	Horizon description
A1	0-4	Very dark gray (10YR 3/1) loam; moderate fine granular structure; friable, slightly sticky, plastic; medium acid; clear wavy boundary.
B21tg	4-16	Dark gray (10YR 4/1) clay; common fine faint dark yellowish brown mottles; moderate coarse prismatic breaking to moderate medium subangular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few fine pores; slightly acid; clear wavy boundary.
B22tg	16-33	Gray (N5/) clay; few fine distinct light olive brown, olive brown and common medium distinct yellowish brown (10YR 5/6) mottles; strong fine angular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; mildly alkaline; clear wavy boundary.
B23tg	33-42	Mottled yellowish brown (10YR 5/6) and gray (N5/) clay; weak fine subangular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; mildly alkaline, gradual wavy boundary.
B24tg	42-60	Mottled greenish gray (5G 6/1) and light olive brown (2.5Y 5/6) clay; weak fine subangular blocky structure; sticky, plastic; broken faint clay films on faces of peds; mildly alkaline.

Location: Berkeley County photo 11T-28. S. C. Highway 45, 0.2 mile SE of Honey Hill tower and 85 feet SW of highway.

Soil Type: Meggett loam Pit No.: 9
Classification: Typic Albaqualfs--fine, mixed, thermic
Drainage: Poorly drained
Relief: Level to nearly level, low-lying areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - Percent by volume - - - - - - -					Inch	Inches
A11	0-2	1.20	54.0	47.5	39.3	23.1	10.0	0.375	0.75
A12	2-7	1.45	43.5	39.5	40.2	25.8	10.6	.289	2.20
B21tg	7-20	1.63	36.2	33.6	37.3	25.3	13.1	.205	4.86
B22tg	20-40	1.56	45.7	44.3	51.7	41.5	26.8	.175	8.36
B23tg	40-54	1.58	44.8	43.2	52.7	41.5	26.9	.163	10.64
B24tg	54-63	1.52	45.4	41.2	45.0	36.5	23.2	.180	12.26

Horizon	Depth Inches	Horizon description
A11	0-2	Very dark gray (10YR 3/1) loam; moderate fine granular structure; friable, slightly plastic; strongly acid; abrupt wavy boundary.
A12	2-7	Dark gray (10YR 4/1) loam; common medium distinct reddish brown (5YR 5/3), dark reddish brown (5YR 3/3) and few fine faint dark grayish brown mottles; moderate fine granular structure; friable; strongly acid; clear wavy boundary.
B21tg	7-20	Dark gray (10YR 4/1) clay; few fine distinct yellowish red, strong brown and yellowish brown mottles; strong coarse prismatic breaking to moderate medium angular blocky structure; very firm; sticky, plastic; broken distinct clay films on faces of peds; few fine pores; slightly acid; clear wavy boundary.
B22tg	20-40	Gray (5Y 5/1) clay; common coarse distinct dark yellowish brown (10YR 4/4, strong brown (7.5 YR 5/6) and few fine distinct yellowish brown mottles; moderate medium angular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few fine pores; mildly alkaline; gradual wavy boundary.
B23tg	40-54	Gray (5Y 6/1) clay; many medium distinct strong brown (7.5YR 5/6) and yellow brown (10YR 5/6) mottles; weak medium angular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few fine pores; mildly alkaline; gradual wavy boundary.

B24tg	54-63	Gray (5Y 5/1) clay; many coarse prominent reddish brown (5YR 4/3) and common fine faint light olive brown mottles; weak fine subangular blocky structure; firm; slightly sticky, plastic; broken distinct clay films on faces of peds; few small quartz and chert gravel 1/8 to 1½ inches in diameter; mildly alkaline; gradual irregular boundary.
IICg	63-74	Pale olive (5Y 6/4) sandy clay loam mixed with shell fragments and marl; many coarse faint olive (5Y 5/6), many medium distinct gray (10YR 5/1), brownish yellow (10YR 6/6) and very dark brown (10YR 2/2) mottles; massive; friable; slightly sticky, slightly plastic; contains gray clay intrusions from above horizon; mildly alkaline.

Location: Berkeley County photo 3T-124. Strawberry Road, approximately 500 feet N of S. C. Highway 402 and 200 feet W of Strawberry Road.

PANTEGO SERIES

Soil Type: Pantego loam Pit No.: 13
Classification: Umbric Paleaquults--fine-loamy, siliceous, thermic
Drainage: Very poorly drained
Relief: Nearly level and slightly depressional areas or drainageways

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - Percent by volume - - - - - - -					Inch	Inches
A11	0-8	0.83	63.6	50.9	29.0	24.4	14.5	0.364	2.91
A12	8-11	1.34	45.0	39.2	32.6	27.5	19.1	.201	3.52
B21tg	11-14	1.54	36.7	31.6	30.7	26.2	17.9	.137	3.93
B22tg	14-26	1.62	38.3	36.2	29.7	25.3	17.6	.186	6.16
B23tg	26-42	1.35	47.7	46.0	36.4	31.2	22.9	.231	9.85
B24tg	42-60	1.30	51.3	49.6	42.5	37.4	26.6	.230	13.99

Horizon	Depth Inches	Horizon description
A11	0-8	Black (10YR 2/1) loam; weak fine granular structure; friable; very strongly acid; clear wavy boundary.
A12	8-11	Black (N2/) loam; weak fine granular structure; friable; very strongly acid; abrupt wavy boundary.
B21tg	11-14	Very dark gray (10YR 3/1) sandy clay loam; few fine faint dark gray and very dark grayish brown mottles; weak fine subangular blocky structure; friable; patchy faint clay films on faces of peds; very strongly acid; clear wavy boundary.
B22tg	14-26	Very dark gray (10YR 3/1) sandy clay loam; common fine faint dark gray and few fine distinct dark yellowish brown mottles; moderate fine subangular blocky structure; friable, slightly plastic; broken faint clay films on faces of peds; very strongly acid; gradual wavy boundary.
B23tg	26-42	Dark gray (10YR 4/1) sandy clay loam; common fine distinct strong brown and yellowish brown mottles and very dark gray mottles in old root channels; moderate medium subangular blocky structure; friable; slightly sticky, slightly plastic; broken distinct clay films on faces of peds; very strongly acid; clear irregular boundary.

B24tg	42-60	Gray (5Y 5/1) sandy clay; many medium faint olive brown (2.5Y 4/4), strong brown (7.5YR 5/6), common coarse distinct dark gray (10YR 4/1) and very dark gray (10YR 3/1) mottles; moderate fine subangular blocky structure; firm; slightly sticky, plastic; broken distinct clay films on faces of peds; very strongly acid.

Location: Berkeley County photo 1T-118. Thompson Branch Road, 0.55 mile NW of Round Pond Road and 30 feet W of Thompson Branch Road.

Soil Type: Pickney sand Pit No.: 16
Classification: Cumulic Humaquepts--sandy, siliceous
Drainage: Very poorly drained
Relief: Nearly level, low-lying or depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - - Percent by volume - - - - - - - -					Inch	Inches
A11	0-8	0.73	70.5	57.2	11.6	9.8	7.2	0.500	4.00
A12	8-16	1.47	45.4	29.5	7.6	5.7	3.3	.262	6.10
A13	16-24	1.67	38.4	34.9	9.2	7.6	5.5	.294	8.45
C1g	24-39	1.38	48.3	43.9	8.2	6.4	4.0	.399	14.43

Horizon	Depth Inches	Horizon description
A11	0-8	Black (5Y 2/1) sand; weak fine granular structure; very friable; many fine roots; very strongly acid; gradual wavy boundary.
A12	8-16	Very dark gray (10YR 3/1) sand; few fine faint black mottles chiefly in old root channels; single grain; very friable; many fine roots; very strongly acid; gradual wavy boundary.
A13	16-24	Very dark gray (10YR 3/1) sand; few fine faint very dark grayish brown and dark grayish brown mottles; single grain; very friable; common fine roots; very strongly acid; gradual wavy boundary.
C1g	24-39	Grayish brown (10YR 5/2) sand; few fine faint dark gray and light brownish gray mottles; single grain; loose; few fine roots; very strongly acid; gradual wavy boundary.
C2g	39-45	Light gray and white (10YR 7/2-8/2) sand; common coarse faint light brownish gray (10YR 6/2) mottles; single grain; loose; very strongly acid; abrupt wavy boundary.
C3g	45-60	Light gray (2.5Y 7/2) sand; common coarse faint light yellowish brown (2.5Y 6/4), olive gray (5Y 5/4), pale olive (5Y 6/4) and brownish yellow (10YR 6/6) mottles; single grain; loose; very strongly acid.

Location: Berkeley County photo 3T-66. Big Ocean Bay on Walleye Road 0.4 mile W of Strawberry Road and 100 feet NE of Walleye Road.

Soil Type: Pickney loamy sand Pit No.: 17
Classification: Cumulic Humaquepts--sandy, siliceous
Drainage: Very poorly drained
Relief: Nearly level, low-lying or depressional areas

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - - Percent by volume - - - - - - - -					Inch	Inches
A11	0-10	1.05	57.7	49.9	19.5	15.8	12.7	0.372	3.72
A12	10-16	1.28	51.5	47.3	16.3	13.6	9.7	.376	5.98
A13	16-30	1.50	44.6	39.6	12.1	10.1	6.1	.335	10.67
C1g	30-40	1.40	46.9	37.3	11.6	9.5	6.5	.308	13.75
C2g	40-48	1.53	43.3	31.4	9.2	8.0	5.7	.257	15.80
C3g	48-60	1.47	45.2	26.3	6.2	5.2	3.0	.233	18.60

Horizon	Depth Inches	Horizon description
A11	0-10	Black (10YR 2/1) loamy sand; weak fine granular structure; very friable; many fine roots; very strongly acid; clear wavy boundary.
A12	10-16	Black (10YR 2/1) loamy sand; weak fine granular structure; very friable; common fine roots; very strongly acid; clear irregular boundary.
A13	16-30	Very dark gray (10YR 3/1) loamy sand; few fine faint very dark grayish brown and very dark brown mottles; weak fine granular structure; very friable; common fine roots; very strongly acid; clear wavy boundary.
C1g	30-40	Grayish brown (10YR 5/2) fine sand; many coarse faint brown (10YR 5/3), very dark gray (10YR 3/1), and very dark grayish brown (10YR 3/2) mottles; single grain; loose; very strongly acid; gradual wavy boundary.
C2g	40-48	Mottled pale brown (10YR 6/3), dark yellowish brown (10YR 4/4), dark brown (10YR 3/3), and very dark grayish brown fine sand; single grain; loose; few small soft concretions; very strongly acid; clear wavy boundary.
C3g	48-60	Mottled pale yellow (2.5Y 7/4), dark grayish brown (10YR 4/2), very dark grayish brown (10YR 3/2) and strong brown (7.5YR 5/6) fine sand; single grain; loose; very strongly acid.

Location: Berkeley County photo 3T-128. Little Ocean Bay on Ten Mile Road, 0.7 mile SE of Ackerman Road and 150 feet SW of Ten Mile Road.

RAINS SERIES

Soil Type: Rains fine sandy loam Pit No.: 14
Classification: Typic Paleaquults--fine-loamy, siliceous, thermic
Drainage: Poorly drained
Relief: Nearly level flats and slight depressions in or adjacent to drainageways

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - Percent by volume - - - - - - -					Inch	Inches
A1	0-6	1.20	50.9	48.4	34.3	26.9	21.0	0.274	1.64
A2	6-11	1.55	40.4	37.9	26.3	21.2	14.3	.236	2.82
B21tg	11-16	1.67	36.4	34.4	28.4	22.0	15.1	.193	3.79
B22tg	16-24	1.65	38.0	36.4	34.5	28.5	20.2	.162	5.08
B23tg	24-45	1.55	42.9	41.1	34.0	29.9	21.2	.199	9.26
B24tg	45-62	1.48	45.4	43.8	31.6	26.8	18.6	.252	13.55
B25tg	62-70	1.61	39.1	35.6	17.3	13.8	8.5	.271	15.72
B3	70-75	1.58	39.8	34.6	17.6	13.8	8.7	.259	17.01
IIC1g	75-92	1.58	39.1	36.2	17.3	13.2	8.2	.280	21.77

Horizon	Depth Inches	Horizon description
A1	0-6	Black (10YR 2/1) fine sandy loam; weak fine granular structure; very friable; very strongly acid; clear wavy boundary.
A2	6-11	Light brownish gray (2.5Y 6/2) fine sandy loam; common fine distinct yellowish brown mottles; weak fine granular structure; very friable; few fine pores; very strongly acid; clear wavy boundary.
B21tg	11-16	Brownish gray (2.5Y 5/2) sandy clay loam; common fine distinct yellowish brown, strong brown and common medium faint very dark grayish brown (10YR 3/2) mottles; weak fine subangular blocky structure; friable, slightly plastic; patchy faint clay films on faces of peds; common fine pores; very strongly acid; clear smooth boundary.

B22tg	16-24	Gray (10YR 6/1) sandy clay loam; common fine distinct brownish yellow and yellowish brown mottles; weak coarse prismatic breaking to moderate fine subangular blocky structure; friable, slightly plastic; broken distinct clay films on faces of peds; common fine pores; very strongly acid; clear wavy boundary.
B23tg	24-45	Gray (10YR 6/1) sandy clay loam; common coarse distinct brownish yellow (10YR 6/6), yellowish brown (10YR 5/6) red (2.5YR 4/6) and dark red (2.5YR 3/6) mottles; weak coarse prismatic breaking to moderate fine subangular blocky structure; friable, slightly plastic; broken distinct clay films on faces of peds; few fine pores; light gray (10YR 7/1) fine sandy loam to fine sand in a few vertical interstices; very strongly acid; clear wavy boundary.
B24tg	45-62	Gray (10YR 6/1) sandy clay loam; many fine faint gray, brownish yellow and few fine distinct strong brown mottles; weak fine subangular blocky structure; friable, slightly plastic; broken distinct clay films on faces of peds; few fine pores; very strongly acid; clear wavy boundary.
B25tg	62-70	Mottled light gray (10YR 7/1), pale yellow (2.5Y 7/4), brownish yellow (10YR 6/6) and yellowish brown (10YR 5/6) sandy clay loam; weak fine subangular blocky structure; friable, slightly plastic; patchy faint clay films on faces of peds; pockets and lenses of sandy loam; very strongly acid; diffuse wavy boundary.
B3	70-75	Brownish yellow (10YR 6/6) fine sandy loam; many fine distinct yellowish brown and strong brown and a few fine faint gray, light gray and pale yellow mottles; weak fine subangular blocky structure; friable; patchy faint clay films on faces of peds; pockets and lenses of fine sandy loam and sandy loam; common mica flakes; very strongly to strongly acid; abrupt wavy boundary.
IIC1g	75-92	Greenish gray (5GY 6/1) interbedded fine sandy loam mottled with light gray (5Y 6/1-7/1); massive; very friable; common mica flakes; mildly alkaline; diffuse irregular boundary.
IIC2g	92-100	Mottled light greenish gray (5GY 7/1) and greenish gray (5GY 6/1) sand and loamy sand; single grain; very friable; neutral to mildly alkaline.

Location: Berkeley County photo 2T-158. Conifer Road, 200 yards NW of Conifer A Road and 70 feet NE of Conifer Road.

SANTEE SERIES

Soil Type: Santee loam Pit No.: 11
Classification: Typic Argiaquolls--fine, mixed, thermic
Drainage: Very poorly drained
Relief: Level to nearly level, low marine terraces

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	Percent by volume					Inch	Inches
A1	0-6	0.27	88.4	77.5	21.7	19.6	16.7	0.608	3.65
B21tg	6-14	.69	73.4	69.6	28.1	25.1	17.9	.517	7.78
B22tg	14-23	1.02	62.5	60.6	36.9	30.7	19.1	.415	11.52
B23tg	23-36	1.27	54.5	51.9	39.7	32.5	18.9	.330	15.81
B24tg	36-48	1.09	62.1	58.8	42.2	35.2	21.4	.374	20.30

Horizon	Depth Inches	Horizon description
A1	0-6	Black (N2/) loam; weak fine granular structure; friable; medium acid; clear wavy boundary.
B21tg	6-14	Black (N2/) clay loam; moderate fine subangular blocky structure; slightly sticky, plastic; patchy faint clay films on faces of peds; slightly acid; clear smooth boundary.
B22tg	14-23	Very dark gray (10YR 3/1) clay; few fine faint olive brown mottles; moderate medium subangular blocky structure; slightly sticky, plastic; patchy faint clay films on faces of peds; slightly acid; gradual wavy boundary.
B23tg	23-36	Dark gray (5Y 4/1) clay loam; few fine faint olive brown mottles; moderate medium subangular blocky structure; slightly sticky, plastic; patchy faint clay films on faces of peds; neutral; gradual smooth boundary.
B24tg	36-48	Dark gray (5Y 4/1) clay; few medium faint olive brown (2.5Y 4/4) mottles; weak medium subangular blocky structure; slightly sticky, plastic; patchy faint clay films on faces of peds; mildly alkaline; gradual wavy boundary.
Cg	48-71	Mottled dark gray (5Y 4/1) and greenish gray (5G 5/1) clay; massive; sticky, plastic; moderately alkaline.

Location: Charleston County photo 3F-14. Thompson Branch Road, 0.25 mile S of Halfway Creek Road and approximately 135 feet W of Thompson Branch Road.

Soil Type: Santee clay loam Pit No.: 10
Classification: Typic Argiaquolls--fine, mixed, thermic
Drainage: Very poorly drained
Relief: Level to nearly level, low marine terraces

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - Percent by volume - - - - - - -					Inch	Inches
A1	0-9	1.18	60.8	46.4	43.0	35.1	25.3	0.211	1.90
B21tg	9-15	1.60	45.3	42.6	48.5	39.1	25.6	.170	2.92
B22tg	15-22	1.60	47.9	43.0	49.2	40.8	26.0	.170	4.11
B23tg	22-39	1.47	50.5	47.9	50.1	41.2	26.2	.217	7.80
B3g	39-48	1.34	55.9	52.7	49.8	41.3	26.2	.265	10.18

Horizon	Depth Inches	Horizon description
A1	0-9	Black (5Y 2/1) clay loam; weak fine granular structure; friable, slightly sticky, slightly plastic; slightly acid; abrupt wavy boundary.
B21tg	9-15	Very dark gray (N3/) clay; few fine faint grayish brown mottles; moderate medium subangular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few small marl nodules; gray (5Y 4/1) sandy clay loam in old root channels; neutral; clear wavy boundary.
B22tg	15-22	Gray (5Y 5/1) clay; common fine distinct olive yellow and few fine faint light olive gray mottles and gray sandy clay loam in old root holes; weak fine subangular blocky structure; firm; sticky, plastic; broken distinct clay films on faces of peds; few small marl nodules; moderately alkaline; gradual wavy boundary.
B23tg	22-39	Gray (10YR 5/1) clay; common fine faint olive yellow and few fine distinct pale olive mottles; moderate medium subangular blocky structure; firm; sticky, plastic; patchy faint clay films on faces of peds; few fine roots; clear wavy boundary.

B3g	39-48	Mottled greenish gray (5GY 5/1 and 6/1), light greenish gray (5G 7/1) and olive yellow (2.5Y 6/8) clay; weak medium subangular blocky structure; sticky, plastic; gray sandy clay loam in old root channels; common marl nodules; neutral.

Location: Charleston County photo 11F-26. S. C. Highway 402, 1.2 mile NW of U.S. Highway 17 and approximately 400 feet SW of S. C. Highway 402

Soil Type: Wahee loam Pit No.: 21
Classification: Aeric Ochraquults--clayey, mixed, thermic
Drainage: Somewhat poorly drained
Relief: Level to nearly level, low marine terraces and terraces along large streams

Horizon	Depth	Bulk density	Total porosity	Moisture at tension of				Available moisture	
				60 cm	1/3 bar	1 bar	15 bars	Per inch	Cumulative
	Inches	G/cm^3	- - - - - - - Percent by volume - - - - - - -					Inch	Inches
A11	0-3	1.11	54.0	41.2	32.6	23.0	11.7	0.295	0.88
A12	3-5	1.51	43.0	36.2	40.2	27.7	16.9	.193	1.27
B21t	5-9	1.52	41.4	36.2	42.6	34.7	23.7	.125	1.77
B22t	9-13	1.55	41.4	39.6	41.8	33.6	21.8	.178	2.48
B23tg	13-35	1.47	44.2	42.7	47.2	39.8	27.1	.156	5.92
B24tg	35-46	1.40	47.6	46.5	43.4	36.3	25.6	.209	8.21
B25tg	46-51	1.28	53.1	51.6	52.4	45.6	31.8	.198	9.20
B3g	51-73	1.79	31.7	27.6	21.8	16.4	11.0	.166	12.86

Horizon	Depth Inches	Horizon description
A11	0-3	Very dark gray (10YR 3/1) loam; weak fine granular structure; friable; many fine medium roots; very strongly acid; abrupt smooth boundary.
A12	3-5	Dark gray (10YR 4/1) loam; common fine faint grayish brown and dark grayish brown mottles; weak fine granular structure; friable; many fine medium and large roots; very strongly acid; abrupt smooth boundary.
B21t	5-9	Light yellowish brown (10YR 6/4) silty clay loam; common fine faint yellowish brown, light brownish gray and pale brown mottles; weak fine subangular blocky structure; friable and slightly plastic; patchy faint clay films on faces of peds; many fine and medium roots; few fine pores; very strongly acid; clear wavy boundary.
B22t	9-13	Grayish brown (10YR 5/2) silty clay loam; many fine prominent strong brown and red mottles; moderate medium subangular blocky structure; firm; broken distinct clay films on faces of peds; common fine and medium roots; few fine and medium pores; very strongly acid; clear wavy boundary.

B23tg	13-35	Gray (10YR 5/1) silty clay; many medium distinct yellowish brown (10YR 5/6) and red (2.5YR 4/6) mottles; moderate medium subangular blocky structure; firm; broken distinct clay films on faces of peds; few fine and medium roots; common fine and medium pores; very strongly acid; gradual wavy boundary.
B24tg	35-46	Gray (10YR 5/1) clay; many medium prominent brownish yellow (10YR 6/6) and red (2.5YR 4/6) mottles; weak fine subangular blocky structure; firm patchy faint clay films on faces of peds; few fine pores; very strongly acid; clear wavy boundary.
B25tg	46-51	Gray (10YR 5/1) clay; many medium distinct yellowish brown and few fine faint grayish brown mottles; weak fine subangular blocky structure; firm; very strongly acid; abrupt irregular boundary.
B3g	51-73	Gray (10YR 6/1) sandy clay loam; few fine distinct yellowish brown and few fine faint grayish brown mottles; weak fine subangular blocky structure; friable; few fine flakes of mica; very strongly acid; abrupt broken boundary.

Location: Berkeley County photo 3T-70. Santee Experimental Forest Watershed Study Unit. 0.8 mile SE of Highway 41 on Conifer Road 40 feet W of Conifer Road.

LITERATURE CITED

Allison, L. E., L. Bernstein, C. A. Bower, and others.
1954. Diagnosis and improvement of saline and alkali soils. U. S. Dep. Agric. Agric. Handb. 60, p. 109-110. Washington, D. C.

Hoover, Marvin D., Louis J. Metz, and David F. Olson, Jr.
1954. Soil sampling for pore space and percolation. USDA For. Serv. Stn. Pap. 42, 28 p. Southeast. For. Exp. Stn., Asheville, N. C.

Long, F. L., J. M. Daniels, F. T. Ritchie, Jr., and C. M. Ellerbe
1963. Soil moisture characteristics of some lower Coastal Plain soils. USDA Agric. Res. Serv. Publ. ARS 41-82, 22 p.

Lutz, J. F.
1970. Movement and storage of water in North Carolina soils. N. C. State Univ. Soil Inf. Ser. 15, 29 p.

Steward, E. H., D. P. Powell, and L. C. Hammond
1963. Moisture characteristics of some representative soils in Florida. USDA Agric. Res. Serv. Publ. ARS 41-63, 53 p.

Hatchell, Glyndon E., and James E. Henderson
1976. Moisture characteristics of some Coastal Plain soils on the Francis Marion National Forest. USDA For. Serv. Res. Pap. SE-150, 44 p. Southeast. For. Exp. Stn., Asheville, N. C.

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SDA Forest Service Research Paper SE-151 June 1976
A 77.2:SE-151

MINIMIZING LOSSES TO FOMES ANNOSUS IN THE SOUTHERN UNITED STATES

BY

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AND

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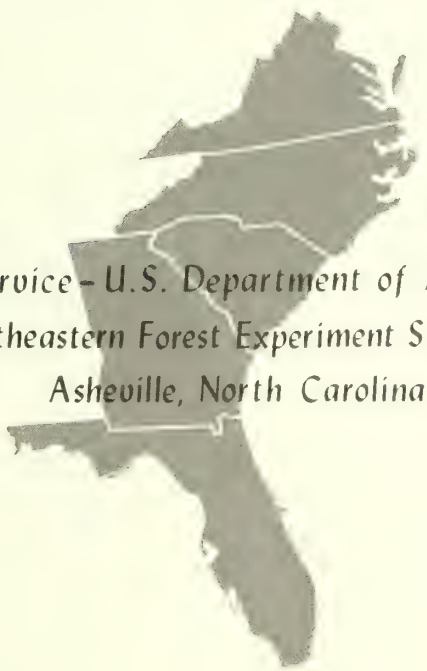

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
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MINIMIZING LOSSES TO FOMES ANNOSUS IN THE SOUTHERN UNITED STATES

by

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Abstract.--Recommended practices to control annosus root rot in southern pine plantations are summarized. Among them are wide spacings, reduced thinnings, and the application of borax to stump surfaces immediately after harvesting. This disease can be easily and economically controlled in the Southern United States if recommended practices are followed.

SUMMARY RECOMMENDATIONS FOR MINIMIZING LOSSES TO FOMES ANNOSUS

1. Delay thinning or reduce the number of thinnings to reduce the risk of loss. Wider spacing and reduced thinnings are beneficial practices.

2. Identify high and low hazard sites so that control procedures can be used routinely on high hazard sites.

3. Sprinkle dry, granular borax liberally on the stump surface immediately after the tree is felled to provide the most positive control by preventing entrance of the fungus into the stand. Borax cannot be used effectively during second or later thinnings if none was applied during initial thinning.

The authors acknowledge the assistance of personnel from the Soil Conservation Service in characterizing and classifying soils in the site hazard evaluation studies.

4. Thin from April to August south of 34° N latitude to provide passive control because of high air and stump temperatures and low number of spores.

5. No special precautions are necessary when replanting sites where F. annosus previously caused damage because the disease will not persist to cause major seedling losses.

6. Plant wisely. Longleaf pine should be planted on high hazard sandy sites because it is more resistant to infection by F. annosus than either loblolly or slash pine.

Procedures for controlling annosus root rot evolved from research throughout the world. From information gained as a result of these studies, several firm recommendations can now be made for the practical control of annosus root rot in southern pine plantations. Apparently many foresters do not utilize the available methods because of uncertainty that damage in their area is sufficient to offset the costs and the inconvenience of disease prevention (6). The purpose of this paper is to present a summary of these recommendations and to give some of the background about their formulation. Although exhaustive study has not been made in all areas of the South, we believe our proposals are generally applicable for the Coastal States from east Texas to Virginia.

The history of Fomes annosus (Fr.) Karst. in the South evolved from a mycological curiosity in 1887 to a major threat to forest production by the late 1950's (fig. 1). Concern was first expressed for the seriousness of the disease in 1954 (4). Following this report, the killing of slash and loblolly pines by this fungus was observed with increasing frequency throughout the Southeast. By 1960, the problem was judged serious enough to justify a survey to determine the extent and severity of losses (35). The survey indicated the disease was widespread throughout the Southeast and Gulf States, and it was present in 59 percent of previously thinned loblolly plantations and 44 percent of thinned slash plantations surveyed. Although overall losses were less than 3 percent, losses in some individual plantations were more than 30 percent. The threat to plantations in the future appeared ominous, since 4.5 million acres were planted to pine in 14 southern states in the 1958-1960 period (1). These plantations were established with the expectation of making regular thinnings at 5- to 7-year intervals beginning when the stands were 12 to 15 years old.

The results of the survey stimulated considerable interest in research and, as a result, practical methods of disease prevention are now available. It is not our intention to rekindle alarm for Fomes. After 15 years of surveillance there is no evidence that this disease will become epidemic in the South. On the other hand, if foresters are complacent, occasional stands will suffer unnecessarily heavy losses.

Figure 1.--Damage caused by Fomes annosus in a heavily infected plantation of slash pine.

ROLE OF THINNING IN SPREAD OF THE DISEASE

In England, Rishbeth (36) presented evidence that the freshly cut stump surfaces were ideal places for spores of F. annosus to germinate (fig. 2). The fungus then grew into the stump roots. If stump roots came in contact with residual tree roots, the fungus colonized the roots of these adjacent trees. The primo facto evidence was the correlation between the percentage of stumps infected one year after thinning with the number of trees affected 7 to 9 years later (38). Although the percentage of trees affected was considerably less than the percentage of stumps infected, the relationship held true for monthly thinnings carried out in two plantations and for a less hazardous third site (38).

Most of the research on F. annosus in the South has positively supported Rishbeth's findings (18). The southwide survey showed that losses increased with the number of thinnings and the years since thinning (35). Ross (43) found

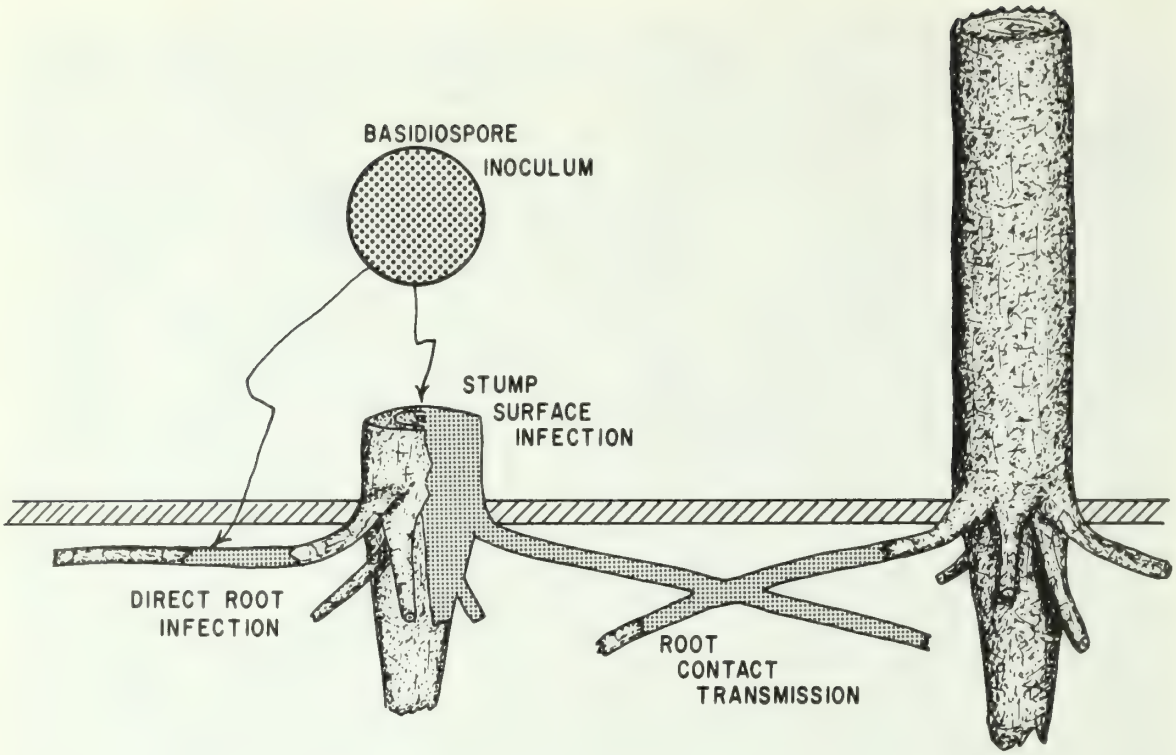

Figure 2.--Diagrams of spores of Fomes annosus landing on a fresh stump surface, germinating, and growing into the stump roots, and causing infection of the residual tree roots at the point of contact of stump and tree roots.

a positive correlation of stumps infected with trees infected in a large seasonal thinning experiment in Bainbridge, Ga. Hodges (21) and Ross and Hodges (unpublished data) cut and inoculated four stumps in otherwise unthinned plots. In 5 years the fungus moved from these inoculated stumps to residual trees up to 10 meters away.

Because annosus root rot is primarily a problem in thinned stands, any change in cultural procedures that delays thinning or reduces the number of thinnings will limit the opportunity for F. annosus to invade a stand. Wider spacing is advantageous because it lengthens the time to the first thinning and reduces the number of thinnings and the potential for root contact. However, on high hazard sites stump treatment or summer thinning is advisable.

An inovation now on the market for harvesting forests, the complete tree harvester developed by Koch (24), may have practical value for preventing infections from F. annosus. By removing the stump and taproot, only the laterals are left in place to provide a possible focal point for new stand infections. We doubt that these roots will provide sufficient energy for the fungus to initiate infection centers.

SITE FACTORS CONTRIBUTING TO DISEASE SEVERITY

Stump infection is essential for disease development; however, stump infection does not always result in disease development. Ross (43) reported higher rates of stump infection near Aulander, N.C., than at Bainbridge, Ga., but losses in the residual stand were negligible at the former and catastrophic at the latter. Kuhlman (28) found that contacts between stump and tree roots occurred nearly 2.5 times more frequently on a similar high hazard site than on this low hazard site. Furthermore, contact resulted in infection five times more frequently on the high than on the low hazard site.

Areas or plantations we designate as high hazard are those where the southwide survey (35), our experience, or similar soil types have indicated that average losses exceed 5 percent of the residual stand. A 5-percent loss in a 400-tree-per-acre stand would result in approximately one cord per acre being lost. We considered areas as low hazard where the average loss has been less than 2 percent.

Prediction equations have been developed (13) for assessing site hazard in the Gulf South; and although further testing has verified their applicability to that area, the important soil variables (organic matter, pH, and texture) are inconvenient to measure. The equations were not applicable to many plantations in the Southeast, and further efforts in constructing a practical prediction model for the entire South have not been successful (Froelich, unpublished; Ross and Hodges, unpublished). The soil parameters evaluated in the latest analyses included organic matter; pH; texture; cation exchange capacity; base saturation; field capacity; wilting point; available P and K; and exchangeable Ca, Mg, K, and Na (Froelich, unpublished). In general, the texture or texture-related variables provided the best discrimination between low and high incidence annosus root rot sites, but none of the equations can be recommended for field use.

Although we cannot offer mathematical models for predicting disease hazard southwide, we can offer qualitative guidelines that will allow foresters to assess annosus hazard with a reasonable degree of accuracy.

Low hazard sites.--The low hazard sites in the South include lowland flatwood soils which never have been cultivated, shallow upland coastal plain soils of the Gulf South which often are marginal or submarginal for agriculture, and piedmont soils of the Southeast which were farmed and then reconverted to forest following severe erosion.

Heavy damage by F. annosus is rare on poorly drained sites or those with high water tables 2 or more months of the year. Soil profiles on these sites usually are mottled. Site quality may range from excellent down to extremely poor as in the phosphorous-deficient sites which require bedding and fertilizing. Surface texture may be either silty or sandy. Pronounced color and texture changes often occur within 8 inches (20 cm) of the surface, with subsoil being of plastic consistency and ashy gray or yellowish in color. Common indicator plants are gallberry (Ilex glabra (L.) Gray) and pitcher plants

(Sarracenia purpures L.). Because of low soil fertility and high water tables, these soils rarely have a history of prior cultivation.

Most soils with heavy clay content within 10 to 12 inches (25 to 30 cm) of the surface are low hazard. The subsurface horizons may resemble those of the wetter sites (plastic texture with yellowish color and mottling) or they may be orange-red and free of mottles. The former sites often contain gallberry, the latter usually occur on rolling terrain and have mixtures of upland hardwoods. We have observed low hazard soils of the Benndale or Ruston series where clay was encountered within 10 to 12 inches (25 to 30 cm) of the surface, but these same series change to high hazard when depth to clay exceeds about 12 inches (30 cm). In some areas of the South, such as near Alexandria or Leesville, La., losses to F. annosus are confined to pockets of deep sand. The seriousness of the disease in those areas therefore depends on the size and distribution of the sand pockets. Groups of more than 50 dead trees have been observed, but the centers of infection stabilize in size as soon as the disease spreads to the shallower soil.

In the Gulf South, hundreds of thousands of acres in plantations are on low hazard sites (fig. 3). The most notable areas are in Winn, Grant, Vernon, Beauregard, Allen, and Washington Parishes in Louisiana; most of the Forest Service land on the Bienville, Chickasawhay, Black Creek, Biloxi, and Homochitto Ranger Districts in Mississippi; and the Conecuh Ranger District in Alabama. Ross (43) describes a similar low hazard site near Aulander, N. C., and the authors have observed additional low hazard sites in the wet land around Panama City, Fla., and Waycross, Ga. Some of the soil series which are consistently associated with low hazard include the Acadia, Caddo, Malbis, Beauregard, Bladen, and Plummer.

High hazard sites.--High hazard sites include both deep sandy or silty soils.

Deep, well-drained sandy soils are extremely hazardous in the Southeast. These soil types occur mainly in the Sand Hills and well-drained areas of the coastal plain. Morris and Frazier (34) defined a high hazard soil as being well drained and a sandy topsoil 10 inches or more in depth. Thick loessial deposits of north Mississippi represent the high hazard silty soils. Ross (43) and Morris (33) reported losses of up to $27 to $30 per acre in 10 years on high hazard sites. Areas of the South that should be considered high hazard for annosus root rot are indicated in figure 3. We want to emphasize that within these broad areas low or moderate hazard areas exist. Each forester must decide how uniform his area is in determining the applicability of our map.

Soil series which have been associated with high hazard include: Eustis, McLaurin, Orangeburg, Cassilla, Lorino silt loam, Lexington, Lucy, Wagram, Woden, Cahaba, Troup, Tifton, Linker, Ruston, Benndale Providence, Memphis, Dulac, and Falaya.

Occasional sites with clay content in excess of 20 percent in the surface 6 inches (15 cm) suffer moderate to heavy losses from Fomes. The most

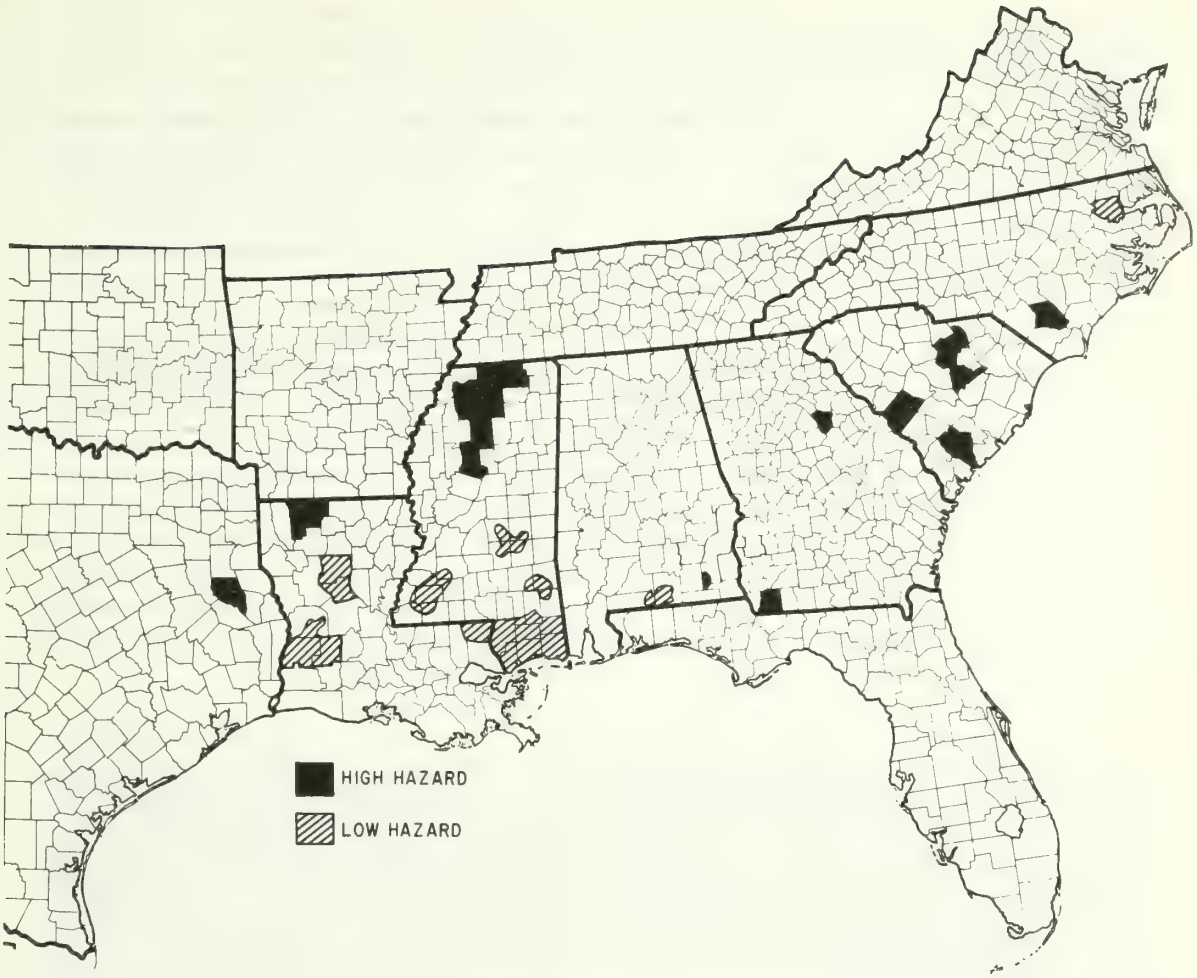

Figure 3.--A map of the Southern United States on which are indicated areas considered to be potentially high or low hazard for damage from annosus root rot. Other areas not marked on the map may also be in these classes but we have not examined these intensively. Please consult the text for criteria to use in evaluating other areas. Areas darkly shaded generally have soils which provide high hazard conditions and on which losses averaging more than 5 percent can be expected. Areas marked with parallel lines generally have soils which provide low hazard conditions and losses averaging 2 percent or less can be expected.

notable examples are near Dadeville in Tallapoosa County, Ala. Two soil series documented by the Soil Conservation Service were Musella and Gwinnett Gravelly loams. Infection centers of these loamy or clayey soil series often are moderately large, with 10 to 20 dead trees per group. Mortality tends to stabilize within 7 years of thinning, but the fungus remains active in roots after this period.

OTHER FACTORS CONTRIBUTING TO DISEASE SEVERITY

Former land use history.--An association between high incidence of annosus root rot and previous land cultivation is commonly expressed throughout the world literature on F. annosus (22). There are notable exceptions,

however, (13) which cast some doubt about the direct effects of previous soil disturbance on the disease. Most low hazard sites were not farmed in the past because of low inherent soil fertility and poor drainage conditions. Thus, initial soil properties may be more important than later soil disturbance. Since we have not been able to determine why certain sites sustain more damage from the disease than others, we have no direct evidence on which to advise foresters about the possible implications of intensive site preparation on disease. We are inclined, however, to suspect that even the most intense site preparations will not alter soil chemical and physical properties significantly and thus increase hazard.

Plantations vs. natural stands.--Current evidence indicates that damage in planted stands is usually greater than in natural stands. It is evident that the former usually are structured and managed differently. Plantations have regular spacing, are thinned uniformly at an early age, and have a continuity of root systems that favor tree-to-tree spread of root rot. Natural stands often are mixed with nonsusceptible species of hardwoods or have irregular density and age structure which results in discontinuous root systems. Furthermore, thinnings at older ages in natural stands leave residual trees by virtue of age more resistant to attack by the fungus, even in cases where infected stump roots are in contact with roots of living trees.

Influence of prescribed burns.--Powers and Verrall (35) first called attention to the observation that high hazard sites have greater accumulations of pine litter on the soil surface than low hazard sites. To a large degree, litter depth is influenced by prescribed fire. There is no evidence to suggest that hazard is altered by litter on low hazard sites, but burning litter on high hazard sites has served to reduce damage over that occurring on unburned plots (12). The practice of prescribed burning currently used in pine plantations should not have an adverse effect on development of annosus root rot.

METHODS OF DISEASE PREVENTION

Once F. annosus becomes established in a forest, there is no practical method short of clearcutting for reducing losses. It is therefore essential that the land manager think in terms of disease prevention rather than control. Particular caution is urged in the management of plantations with high special use potential such as recreation areas, seed orchards, and watersheds. Fortunately, root rot is very easy and economical to prevent. Since stumps are the focal points for almost all new stand infections, disease prevention methods are directed toward the minimization of numbers of infected stumps. This can be accomplished by: (1) using stump protectants to prevent disease entry, (2) restricting thinnings to low-risk seasons of the year, and (3) reducing the number of thinnings during a rotation.

Stump protectants.--Rishbeth (36) creosoted fresh stump surfaces to show that less infection occurred in these stumps than in untreated stumps. Because creosote reduced stump infection, the British Forestry Commission immediately adopted creosoting as a control procedure against F. annosus in first thinnings. Most initial control efforts in the South also included creosote

until it was found to have limited effectiveness (29, 37, 39). Subsequently, a number of other chemicals were tested including paint, nitrates, nitrites, urea, formalin, disodium octaborate, and borax (7, 8, 14, 19). In 1963, Driver (7) reported that dry granular borax prevented stump surface infection by F. annosus in a slash pine plantation. This control has been substantiated by others (2, 11, 19, 23, 25), and is considered the most effective, cheapest, and safest chemical tested to date. Borax is the only chemical currently registered for use as a stump treatment against F. annosus in the United States.

a. Borax--Borax is applied "saltshaker" style to the stump surface immediately after the tree is cut. A round plastic container which holds about 1 pound (about 1 liter in volume) is the most efficient size. Five holes, 3 mm in diameter, drilled in the 5-cm lid allow the borax to flow fast enough to cover the stump quickly. For a thinning operation that removes 60 square feet of basal area per acre, 5 pounds of borax per acre is needed (20). Granular borax is not hygroscopic and flows freely even in wet weather. Enough borax is put on the stump to give a light, uniformly white coating (fig. 4). The entire stump surface and any exposed wood on the sides must be covered. Resin exudation prevents the borax from being washed off even on severely slanted

Figure 4.--Pine stump covered with a light uniform coating of borax.

stumps. The addition of powdered tree-marking paint, powdered concrete, or similar dyes to the borax will facilitate checking the application and ensure uniform treatment. Several forest managers stipulate in the contract a fine for any untreated stumps. It is essential that all stumps are treated. Borax protects by sealing the stump surface, but has no effect below ground. If untreated stumps become infected, the fungus can spread to treated stumps through root contacts.

Stump treatment with borax should be carried out immediately after the tree has been felled. The stumps are immediately open to infection by airborne spores and if treatment is delayed to the end of the day or the week, the treatment will be considerably less effective. Stumps are susceptible to infection up to 2 weeks after exposure (5, 41).

After application, borax penetrates rapidly into the stump to a depth of 1 to 2 inches where it remains at levels toxic to F. annosus up to 2 years after application (25). Although toxic to F. annosus in the stumps, the amount of boron added to the plantation (environment) is negligible. Hodges (20) applied 20 to 30 g of boron/0.1-acre plot.

The most practical means of application is by the man felling the trees immediately treating the stump. The applicator is kept in the feller's pocket or in a holder attached to his belt. The fellers become quite adept in applying borax and each one develops his own technique of application. In operations where the pulpwood sticks are piled for loading by winch or other mechanical loader, stumps can be treated by the worker when he picks up the stick adjacent to the stump. This system works well only when the workers who do the piling do not have to help with the loading and work closely behind the feller(s). Having one man who does nothing but treat stumps is inefficient and not practical. Treating stumps after an area has been harvested results in many missed stumps.

Is stump treatment with borax economically feasible? Recent cost analyses by Hodges (20) indicated the cost of stump treatment in the first thinning was slightly less than 27¢ per cord for labor and materials. This figure did not include overhead and interest. If 10 cords per acre were cut, cost of treating would be $2.70 per acre. On high hazard areas, if the average loss of one cord worth $8 is prevented, the cost/benefit ratio is 1/3. The cost/benefit ratio on low hazard sites would average 1/1.

Will treating stumps affect production? Harvesting (fell, partially limb and buck) time per cord of wood on 0.1-acre plots where no down or idle time was experienced averaged an additional 3 minutes per cord for stump treatment out of a total time of 25 to 30 minutes (20). Since up to 38 percent of the total harvest time in normal operations is spent doing jobs not directly related to harvesting operations (31), it is unlikely that treating stumps will have any noticeable effect on total daily production by a pulpwood crew. In addition to these factors, many crews routinely work toward daily truckload goals rather than maximum production.

Borax can be used in previously unthinned stands or in previously thinned stands that have no annosus present. However, the latter condition is difficult to determine. If roots are already infected through contact with infected stump roots from a previous thinning, the stump protectant will not prevent expanded growth of the fungus throughout the root system. In these circumstances, stump protectants may actually facilitate colonization of the stump by F. annosus by preventing microbial competitors of F. annosus from entering at the stump surface and by preserving the stump life. In previously thinned but untreated stands on high hazard sites, summer thinning or application of Peniophora gigantea are preferred over borax treatment.

Some stump roots are infected directly by F. annosus spores that filter down through the soil (fig. 2) (16, 19, 26). Direct root infection provides a means for the fungus to establish itself even when stump protectants are applied. However, because less than 10 percent of the stump roots are infected in this manner (16, 19), the impact on the effectiveness of the borax treatment is minor.

b. Peniophora gigantea--Among the many organisms which grow in stumps, Peniophora gigantea is the most vigorous competitior of Fomes (3, 11, 19, 29, 32, 40, 41), and has been used effectively as a stump protectant (11, 20, 40). Peniophora has been cleared by the Environmental Protection Agency for use and is being sold commercially. As a stump treatment, Peniophora is somewhat more difficult to use than borax. The fungus will be sold as spores which must be made up into a water suspension. Applied with plastic spray bottles at a rate of 2 to 4 cc per stump, Peniophora will cost about 10¢ to 12¢ per cord more than borax (20). Preliminary studies (Ross and Hodges, unpublished) indicate that Peniophora colonizes mechanically sheared stumps, and attempts are being made to perfect accessories for use with mechanical harvesters. For mechanized logging, Peniophora has much greater potential than borax which is relatively insoluble in water.

Summer thinning.--The long hot summers in the Southern United States have been shown to provide passive control of the disease. Many of our early stump-treatment studies established in late spring were unsuccessful because of the low rates of stump infection in the inoculated check treatments. Driver and Ginns (9) reported considerably fewer infection centers in a plantation thinned in July-August versus an adjacent one thinned in January-February. The low rate of stump infection in the summer is due to thermal inactivation of spores and mycelium of the fungus and to the low rate of spore production. Spores of F. annosus were killed by 1-hour exposure to 113° F (45° C) (42). Mycelium growing in wood was killed after 2-hour exposure at 104° F (40° C) (15). Stump surface temperatures frequently reached 104° to 113° F from May to August in Georgia, South Carolina, and North Carolina (42).

By thinning each month during the year, Ross (43) demonstrated that infection of residual trees occurred most readily from stumps of trees cut from October to February. In the period of April through August, very few spores of F. annosus are produced, and mean daily temperatures of 70° F (21° C) and

maximum temperatures of 90° F (32° C) combine to result in low rates of stump infection (11, 43). Ross (43) recommended thinning from April to August below 34° N latitude (approximately Wilmington, N.C., Columbia, S.C., Atlanta, Ga., and Gadsden, Ala.) to minimize risk of damage from this disease. Some forest managers may want to thin in summer on high hazard sites and thin during the rest of the year on low hazard sites to avoid any control costs.

North of 34° N latitude, other methods of control should be used on high hazard areas. Although mean daily temperatures of 70° F have been correlated with a reduction in residual tree mortality, it cannot be assumed that a daily mean above 70° F on the day the stump is exposed will preclude the disease. Since stumps are susceptible to infection for at least 2 weeks, the weather during that period, stand density, and availability of spores are all important.

REFORESTATION

In Europe, reforestation of sites where the previous forest was diseased has resulted in a long-term economic drain because losses in the second rotation continued up through 40 years. In the South initial seedling losses following reforestation appeared dramatic, but, after 5 years, losses were insignificant (10, 17, 30). Overall losses after 8 years averaged less than 5 percent. The most dramatic initial damage was on sites where the previous stands were clearcut because of fusiform rust or age, not F. annosus (17). On these sites, stump infection took place when the stand was clearcut and the uniform colonization caused losses by F. annosus to occur after 3 to 4 years. These losses tapered off to nearly zero by age 8. Many slash pine seedlings in a Florida plantation had F. annosus conks at age 4 but were still alive at age 8 with no further evidence of infection (fig. 5).

Stumps decompose rapidly under the mild conditions in the South. Whereas stumps may persist up to 40 years in Europe, in the South only a bark shell is evident after 5 to 10 years from pulpwood-sized trees. Therefore, although the spread to young seedlings is rapid, the stump and seedling wood soon disappear, to eliminate the disease.

RESISTANCE

We have had limited success in identifying sources of resistance in southern conifers. Greenhouse tests were initially promising but finally indicated small inter- and no intraspecific variation in susceptibility (27). Field inoculations of loblolly, longleaf, and slash pine indicate longleaf is more resistant than the other two, on the basis of infection, spread, and mortality (21). Longleaf could be used to reduce the risk of loss to F. annosus on sandy, high hazard soils.

Figure 5.--Four-year-old slash pine infected by Fomes annosus because its roots made contact with an infected stump. Note the F. annosus conk on the main stem.

LITERATURE CITED

(1) Anonymous
1960. Annual planting report 1960. USDA For. Serv. Tree Plant. Notes 44, 13 p.

(2) Artman, J. D., D. H. Frazier, and C. L. Morris
1969. Fomes annosus and chemical stump treatment in Virginia--a three-year study. U.S. Dep. Agric. Plant Dis. Rep. 53:108-110.

(3) Boyce, J. S., Jr.
1963. Colonization of pine stem sections by Fomes annosus and other fungi in two slash pine stands. U.S. Dep. Agric. Plant Dis. Rep. 47:320-324.

(4) Campbell, W. A., and G. H. Hepting
1954. Fomes annosus on slash pine. U.S. Dep. Agric. Plant Dis. Rep. 38:217.

(5) Cobb, F. W., Jr., and R. A. Schmidt
1964. Duration of susceptibility of eastern white pine stumps to Fomes annosus. Phytopathology 54:1216-1218.

(6) Collicott, L. V.
1974. Fomes annosus-1974 Survey. Southlands Exp. For. For. Res. Notes, Tech. Note 33, 6 p., Bainbridge, Ga.

(7) Driver, C. H.
1963a. Borax--a control of pine stump surface infection by Fomes annosus. Southlands Exp. For. For. Res. Notes, Tech. Note 18, 4 p., Bainbridge, Ga.

(8) Driver, C. H.
1963b. Further data on borax as a control of surface infection of slash pine stumps by Fomes annosus. U.S. Dep. Agric. Plant Dis. Rep. 47:1006-1009.

(9) Driver, C. H., and J. H. Ginns, Jr.
1964. The effects of climate on occurrence of annosus root-rot in thinned slash pine plantations. U. S. Dep. Agric. Plant Dis. Rep. 48:509-511.

(10) Driver, C. H., and J. H. Ginns, Jr.
1965. Annosus root-rot in young southern pines planted on an infested site. U.S. Dep. Agric. Plant Dis. Rep. 48:803-807.

(11) Driver, C. H., and J. H. Ginns, Jr.
1969. Ecology of slash pine stumps: fungal colonization and infection by Fomes annosus. For. Sci. 15:2-10.

(12) Froelich, R. C., and T. R. Dell
1967. Prescribed fire as a possible control of Fomes annosus. (Abstr.) Phytopathology 57:811.

(13) Froelich, R. C., T. R. Dell, and C. H. Walkinshaw
1966. Soil factors associated with Fomes annosus in the Gulf states. For. Sci. 12: 356-361.

(14) Ginns, J. H., Jr., and C. H. Driver
1969. Annosus root-rot in slash pine plantations four years after thinning and stump treatments. U.S. Dep. Agric. Plant Dis. Rep. 53:23-25.

(15) Gooding, G. V., Jr., C. S. Hodges, Jr., and E. W. Ross
1966. Effect of temperature on growth and survival of Fomes annosus. For. Sci. 12:325-333.

(16) Hendrix, F. F., Jr., and E. G. Kuhlman
1964. Root infection of Pinus elliottii by Fomes annosus. Nature 201(4914):55-56.

(17) Hendrix, F. F., E. G. Kuhlman, C. S. Hodges, Jr., and E. W. Ross
1964. Fomes annosus--a serious threat to regeneration of pine. U.S. For. Serv. Res. Note SE-24, 4 p. Southeast. For. Exp. Stn., Asheville, N.C.

(18) Hodges, C. S.
1969. Modes of infection and spread of Fomes annosus. Annu. Rev. Phytopathol. 7: 247-266.

(19) Hodges, C. S.
1970. Evaluation of stump treatment chemicals for control of Fomes annosus, p. 43-53. In C. S. Hodges, J. Rishbeth, and A. Yde-Andersen [ed.], Proceedings of the third international conference on Fomes annosus (1968). [IUFRO] USDA For. Serv., Washington, D.C.

(20) Hodges, C. S.
1974a. Cost of treating stumps to prevent infection by Fomes annosus. J. For. 72: 402-404.

(21) Hodges, C. S., Jr.
1974b. Relative susceptibility of slash, loblolly and longleaf pines to infection by Fomes annosus, p. 86-91. In E. G. Kuhlman [ed.], Proceedings of the fourth international conference on Fomes annosus (1973). [IUFRO] USDA For. Serv., Washington, D.C.

(22) Hodges, C. S., J. W. Koenigs, E. G. Kuhlman, and E. W. Ross
1971. Fomes annosus: A bibliography with subject index--1960-1970. USDA For. Serv. Res. Pap. SE-84, 75 p. Southeast. For. Exp. Stn., Asheville, N.C.

(23) Johnson, D. W., and E. B. Cowling
1965. Role of pinosylvins and borax in control of Fomes annosus by stump treatments. Phytopathology 55:1341-1346.

(24) Koch, P.
1974. Why not take all of me. For. Farmer 33(10):12-13.

(25) Koenigs, J. W.
1969. Growth and survival of Fomes annosus at high concentrations of borax. Phytopathology 59:1717-1721.

(26) Kuhlman, E. G.
1969. Number of conidia necessary for stump root infection by Fomes annosus. Phytopathology 59:1168-1169.

(27) Kuhlman, E. G.
1972. Susceptibility of loblolly and slash pine progeny to Fomes annosus. USDA For. Serv. Res. Note SE-176, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

(28) Kuhlman, E. G.
1974. Variation in infection of loblolly pine roots on high and low hazard sites in the Southeastern United States, p. 179-183. In E. G. Kuhlman [ed.], Proceedings of the fourth international conference on Fomes annosus (1973). [IUFRO] USDA For. Serv., Washington, D.C.

(29) Kuhlman, E. G., and F. F. Hendrix, Jr.
1964. Infection, growth rate, and competitive ability of Fomes annosus in inoculated Pinus echinata stumps. Phytopathology 54:556-561.

(30) Kuhlman, E. G., and E. W. Ross
1970. Regeneration of pine on Fomes annosus-infested sites in the Southeastern United States, p. 71-76. In C. S. Hodges, J. Rishbeth, and Yde-Andersen [ed.], Proceedings of the third international conference on Fomes annosus (1968). [IUFRO] USDA For. Serv., Washington, D.C.

(31) Lewis, G.
1968. Needed: better management and supervision in logging operations. For. Farmer 27(12):6-8, 18.

(32) Meredith, D. S.
1960. Further observations on fungi inhabiting pine stumps. Ann. Bot. N.S. 24: 64-78.

(33) Morris, C. L.
1970. Volume losses from Fomes annosus in loblolly pine in Virginia. J. For. 68: 283-284.

(34) Morris, C. L., and D. H. Frazier
1966. Development of a hazard rating for Fomes annosus in Virginia. U.S. Dep. Agric. Plant Dis. Rep. 50:510-511.

(35) Powers, H. R., Jr., and A. F. Verrall
1962. A closer look at Fomes annosus. For. Farmer 21(13):8-9, 16-17.

(36) Rishbeth, J.
1951. Observations on the biology of Fomes annosus, with particular reference to East Anglian pine plantations. II. Spore production, stump infection, and saprophytic activity in stumps. Ann. Bot. 15:1-22.

(37) Rishbeth, J.
1952. Control of Fomes annosus Fr. Forestry 25:41-50.

(38) Rishbeth, J.
1957. Some further observations on Fomes annosus Fr. Forestry 30:69-89.

(39) Rishbeth, J.
1959. Stump protection against Fomes annosus. I. Treatment with creosote. Ann. Appl. Biol. 47:519-528.

(40) Rishbeth, J.
1963. Stump protection against Fomes annosus. III. Inoculation with Peniophora gigantea. Ann. Appl. Biol. 52:63-77.

(41) Ross, E. W.
1968. Duration of stump susceptibility of loblolly pine to infection by Fomes annosus. For. Sci. 14:206-211.

(42) Ross, E. W.
1969. Thermal inactivation of conidia and basidiospores of Fomes annosus. Phytopathology 59:1798-1801.

(43) Ross, E. W.
1973. Fomes annosus in the Southeastern United States: Relation of environmental and biotic factors to stump colonization and losses in the residual stand. U.S. Dep. Agric. Tech. Bull. 1459, 26 p.

Kuhlman, E. G., C. S. Hodges, Jr., and R. C. Froelich
1976. Minimizing losses to Fomes annosus in the Southern United States. USDA For. Serv. Res. Pap. SE-151, 16 p. Southeast. For. Exp. Stn., Asheville, N.C.

Recommended practices to control annosus root rot in southern pine plantations are summarized. Among them are wide spacings, reduced thinnings, and the application of borax to stump surfaces immediately after harvesting. This disease can be easily and economically controlled in the Southern United States if recommended practices are followed.

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A Forest Service Research Paper SE-152 June 1976

Aid for Maintaining Air Quality During Prescribed Burns in the South

by

James A. Pharo

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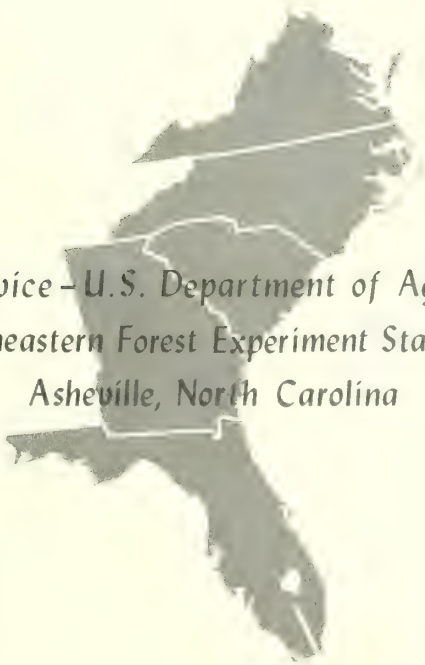

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Aid for Maintaining Air Quality During Prescribed Burns in the South

by

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Abstract.--With the method presented, southern forest managers can decide when a prescribed burn is unlikely to create enough particulate to exceed air quality standards. The aid, which is based upon the atmosphere's ability to disperse particulate, is probably as good as can be produced at present. A single graph, amenable to change without jeopardizing the method, is offered as a basic decision aid.

Keywords: Smoke management.

This paper offers forest managers a simple way to include air quality criteria in their fire prescriptions. Given any of a wide range in fuel and atmospheric conditions, it says whether or not to burn. Hence, it leaves little decisionmaking to the manager. A more detailed guide, "Managing Smoke From Prescription Burning in the South," will soon be published.[1] It will cover chemical, fuel and dispersion criteria in depth. Unlike the present paper, therefore, the one that follows will present a way to estimate the consequences of a fire, weigh the alternatives, and then proceed according to individual dictates.

Wood smoke from prescribed burning can be very undesirable under certain atmospheric conditions. Forest managers, therefore, should prescription burn when atmospheric conditions favor smoke dispersion. Sufficient information is not yet available to predict exactly how much smoke will be produced or exactly how rapidly it will disperse (Mobley, Brender, and Williams 1975). This paper therefore presents a relatively conservative method for deciding when to burn. Thus, forest managers who follow the procedure described can be sure of maintaining an acceptable air quality level. Their fires will not exceed the atmosphere's natural dispersion ability, which is implied by visibility observations. The theoretical considerations on which this procedure is based were described in an earlier paper (Pharo and Hauck 1975).

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[1]This detailed management guide is scheduled for publication in 1976.

To use this aid, forest managers must compute a fuel factor for each stand and they must obtain a ventilation estimate for the area and time of burning. The fuel factor represents the initial particulate concentration a fire puts into the air. Ventilation represents the atmosphere's natural ability to disperse that concentration. The combined effects of particulate emission (fuel factor) and atmospheric dispersion (ventilation) determine the particulate concentration at a location. This concentration may be observed as a reduction in horizontal visual range or visibility.

Small increases in particulate concentrations are sometimes unacceptable in certain locations. When increases reduce visibility at scenic vistas, obscure highways, or put an airport on instrument flight regulations, a prescribed fire should be postponed.

Burning should never be prescribed during air pollution warnings, alerts, or episodes. This paper lists conditions that should be met before a prescribed fire is ignited, and it provides a safe and easy way to decide when some smoke is tolerable.

VISIBILITY AND SMOKE CONCENTRATION

Wood smoke contains several chemical components that are considered pollutants. State and federal agencies have defined legal levels for some pollutants through legislation. Southern States either exempt open burning or they use a permit system (Brender and Mobley 1974; Craig 1973). A permit system is an indirect way of defining an acceptable smoke concentration by designating acceptable prescribed burning periods. Federal standards have been published (Environmental Protection Agency 1971) that may be applied indirectly to burning programs. Particulate matter, one of six common air pollutants, is an important component in wood smoke (Murphy and others 1970). Particulate matter decreases visibility. The secondary federal standard for particulate matter is equivalent to almost a 5-mile average visibility for 24 hours (Fritschen and others 1970, p. 21).

The equivalency between particulate matter and visibility helps define an acceptable smoke concentration. If a prescribed fire reduces visibility downwind to 0.5 mile for 1 hour, then a visibility of 9 miles for the remaining 23 hours of that day would comply with the federal standard. A sustained visibility reduction to 0.5 mile for more than 2 hours violates national standards. Visibility reductions to 0.5 mile for more than 0.5 hour are not recommended during a fire; 0.5 mile is also twice the safe stopping distance for most vehicles traveling 70 miles per hour.

Federal ambient air quality standards for particulate can be easily met if background visibility before a fire is 5 or more miles. Visibility estimates for the general location of a prescribed fire can be obtained from the National Weather Service; however, these estimates can be made by local fire-tower operators. Tower operators are trained to estimate visibility, and they have known distance markers available to them. Their visibility estimates, if in error, will tend to be an underestimate because trained observers usually underestimate the true visibility (Middleton 1968, p. 220).

FUEL FACTOR

The fuel factor is defined as the particulate emission rate per unit length of fire front. It is the product of available fuel per unit area (tons per acre that burn) and fire spread rate (chains per hour). Only rough estimates of available fuel and spread rates, accurate to ± 2 tons per acre and ± 1 chain per hour, are necessary to use this aid.

AVAILABLE FUEL

Available fuel is difficult to estimate and very little has been published to help the forest manager. In some slash-longleaf stands where total fuel weights varied from 7.0 to 19.5 tons per acre, Hough (1968) found an average total fuel reduction (available fuel) of 50 percent. In longleaf stands in Florida and Georgia, Sackett (1975) found a nearly linear relationship between available fuel and age of rough up to 12 years. McNab and Edwards found similar results in slash pine roughs.[2] Table 1 combines Sackett's and McNab and Edwards' study results. It presents a direct relationship between age of rough and available fuel; the values shown are fairly consistent with observations in slash-longleaf stands on mineral soil.[3] Available fuel in table 1 probably applies best to areas where the site index is between 60 and 95.

Table 1.--Guide for estimating available fuel under longleaf, slash, or loblolly pine stands with typical palmetto-gallberry understories, given age of rough

Age of rough (years)	Fuel
	Tons/acre
1	2.5
2	3.2
3	4.0
4	4.9
5	5.7
6	6.6
7	7.5
8	8.3
9	9.0
10	9.9
11	10.7
12	11.6

Available fuel can also be estimated for loblolly or slash pine stands that have been logged. Loblolly pine residue weight is related to the number of harvested cords per acre. To estimate the available slash weight, multiply the number of cords per acre or their board-foot equivalent (1,000 board feet equals 3 cords) by 0.1 ton per cord. For example, 16 cords per acre yields 1.6 tons of available fuel per acre. In this estimating procedure, it is assumed that needles and branchwood less than one-half inch in diameter are available fuel and that minimum merchantable top diameters are 4 inches (Wade 1969).

[2]W. Henry McNab and M. Boyd Edwards, Research Forester and Research Ecologist, respectively, at the Southern Forest Fire Laboratory, Macon, Georgia, shared preliminary total fuel data from a study in progress.

[3]Personal communication with North Carolina Forest Service employees John G. Shepherd and William B. Flanner; they are, respectively, Staff Forester, Fire Control, Box 27687, Raleigh, N.C. 27611, and Project Leader, Rt. 7 Box 88, Kinston, N.C. 28501.

SPREAD RATE

Spread rate, the other variable in the fuel factor, depends upon several variables, including firing technique, relative humidity, days since last 1/4-inch or more of rainfall, or moisture content of fresh litter layer. The average spread rate for backfires in slash-longleaf pine stands with typical palmetto-gallberry understories is between 0.8 and 3.0 chains per hour (Hough 1968). Figure 1 can be used to estimate a spread rate for backfires. Its greatest potential is found using relative humidity and days since 1/4-inch rainfall to determine spread, since estimating moisture content without oven-drying samples is risky. The dashed arrows highlight the requirements for a 2-foot per minute (1.8 chains per hour) spread in figure 1, 6 days since last 1/4-inch rainfall, and 50-percent relative humidity or a known moisture content of 20 percent. Use of this figure is justifiable because backfires spread at fairly uniform rates.

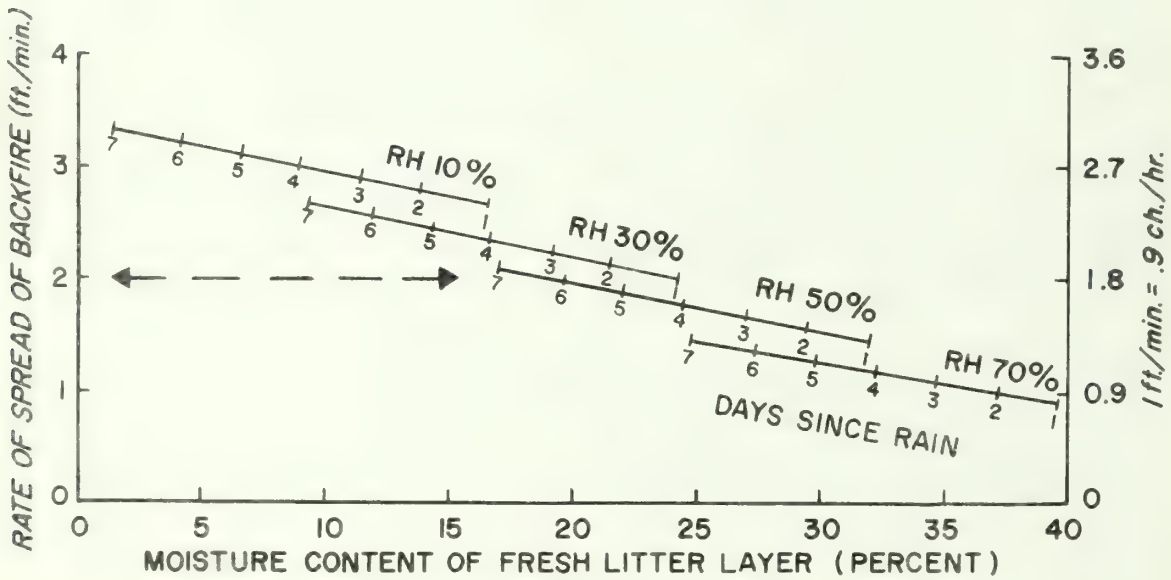

Figure 1.--Rate of spread of backfires as a function of relative humidity adjusted for either moisture content of the fresh litter layer or the number of days since one-quarter inch or more of rain (adapted from Hough (1968)).

Other firing methods produce widely varied spread rates. Spread rates for flank fires and head fires often depend upon windspeed and several fuel variables. Given the same or similar weather and fuel conditions, spread rates for head fires differ from those of flank fires. For ease of application, assume that all fires other than backfires are head fires. Head fire spread rates up to 30 chains per hour have been observed during safe prescribed burns in pine stands with typical palmetto-gallberry understories.[4]

[4]Personal communication with Dale D. Wade, Research Forester, South. For. Fire Lab., Macon, Ga.

AVAILABLE FUEL AND SPREAD RATE

The fuel factor is the product of estimated available fuel per unit area (tons per acre that will burn) and fire spread rate (chains per hour). It expresses a prescribed fire's smoke production rate per unit length of fire.

The fuel factor (F) for a fire that consumes 4 tons per acre and spreads at a rate of 2 chains per hour is:

F = 8 ton-chains/acre-hour.

The suggested references, table, and figure 1 produce very crude estimates of fuel weights and spread rates. If forest managers know these fuel estimates are erroneous, they probably already have a better way to estimate them. Forest managers are encouraged to use any reliable methods at their disposal. Weights and spread rates will be covered in depth in the "Managing Smoke from Prescription Burning in the South."

VENTILATION

The atmosphere's ability to disperse smoke depends upon the volume of air available for mixing. This volume is estimated as "ventilation," which is defined as the product of mixing height and the transport windspeed. Information on mixing height and transport windspeed for an area and time is available from the National Weather Service (Gross 1970).

MIXING HEIGHT

Mixing height is the height above ground where mixing occurs. It is obtained by analysis of upper-air soundings taken twice daily at various locations. Thus, two mixing heights, morning and afternoon, are reported daily. Typical morning and afternoon mixing heights range from 300 meters (about 980 feet) to 1,400 meters (about 4,600 feet) during autumn (Holzworth 1972). Mixing heights depend upon location and time; however, the values obtained from the nearest weather station are assumed to be representative of those at fire sites. Afternoon mixing heights correspond to the times when most daytime burning is accomplished. Morning mixing heights are more representative of nighttime conditions.

TRANSPORT WINDSPEED

Transport windspeed is the arithmetic mean of the windspeed from ground level to the mixing height. It too is obtained from an analysis of data from upper-air soundings. Typical transport windspeeds range from 4 to 8 meters per second during autumn in the Southeast (Holzworth 1972). Transport windspeeds also depend on location and time. Although fire sites are remote from measurement sites, such data have been successfully used in agriculture burning programs (Thuiller and Sandberg 1972). Afternoon mixing heights are multiplied by transport windspeed to obtain ventilation.

Ventilation for a mixing height of 2,000 meters and a transport windspeed of 10 meters per second is:

V = 20,000 square meters/second.

The curious mix of units given above is intentional. Generally, forest managers are familiar with the units given for fuel factors. Components of ventilation are usually reported in metric units. Conversions for comparisons between fuel and ventilation are unnecessary; they have been included in the developmental process of this method which is reported elsewhere (Pharo and Hauck 1975).

WHEN TO BURN

To apply the method described here, a forest manager must consider fire type (head fire or backfire), fuel factor, and ventilation. These considerations are displayed in figure 2. But there are other considerations. BURNING SHOULD NEVER BE DONE:

1. During an air pollution warning, alert, or episode.
2. When the visibility is less than 5 miles.
3. When the relative humidity is more than 70 percent.
4. When a smoke-sensitive area is less than 40 chains downwind.
5. When figure 2 indicates NO BURN.

Figure 2 is offered to aid forest managers in deciding when to burn. Fuel factors are along the horizontal axis and ventilation factors are along the vertical axis (0 to 12,000 for backfires, 0 to 24,000 for head fires).

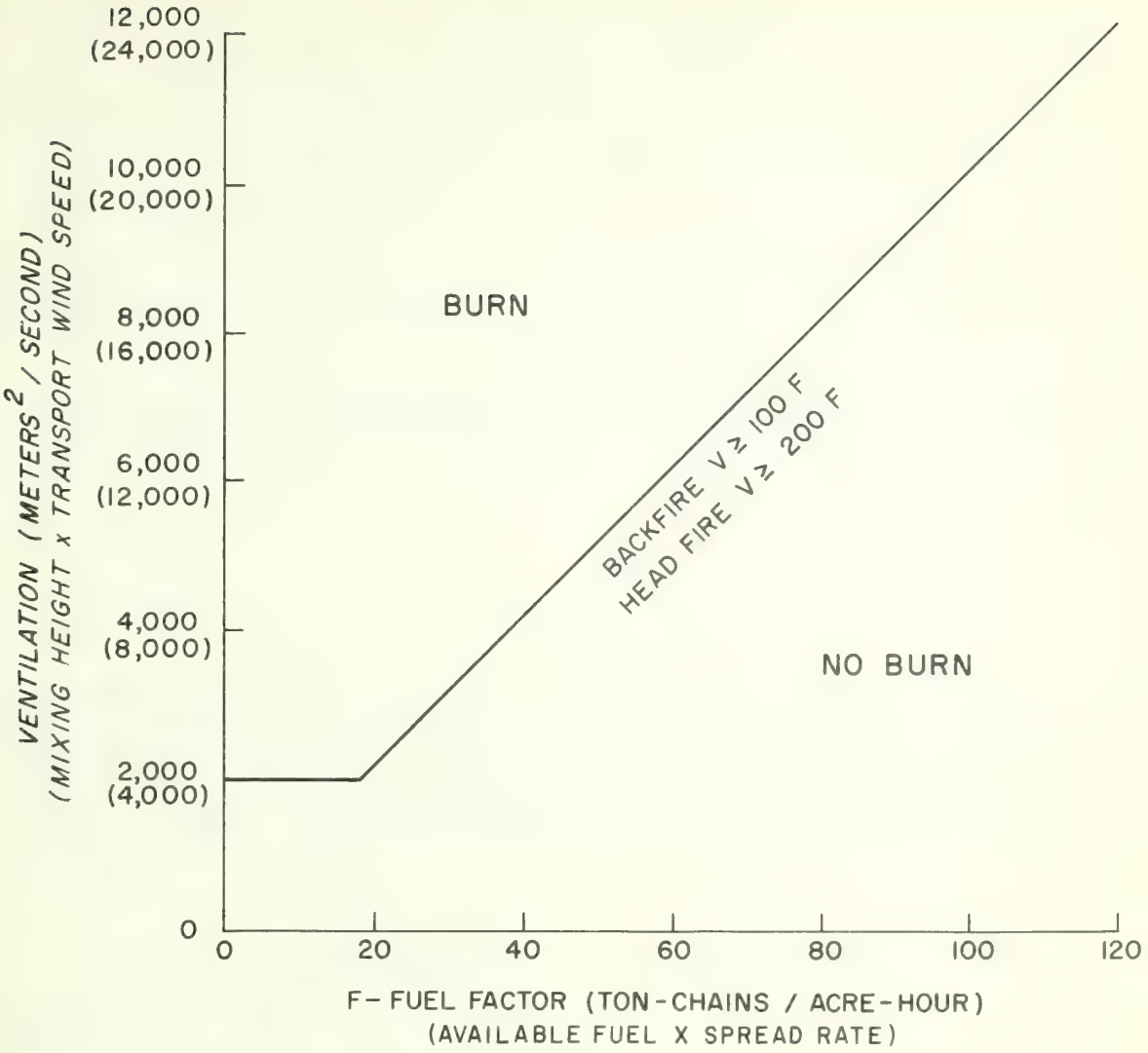

Figure 2.--Burn only when the combination of ventilation and fuel factors falls above the line on the graph.

The minimum acceptable ventilation for backfires is 2,000. Fuel factors for prescribed fires in the South seldom exceed 15 or 20 ton-chains per hour; however, fires should not be ignited until the mixing height is at least 500 meters and the ventilation factor is 2,000 square meters per second.[5] This is why the interior line separating burn and no-burn situations is horizontal between fuel factors 0 and 20. The area below the interior line encompasses fuel and ventilation combinations that will reduce visibility to 0.5 mile or less somewhere beyond 40 chains downwind of the fire. Fuel factor and ventilation combinations that occur below the line indicate that burning should not be done.

[5]Personal communication with Lewis H. Nagler, Meteorologist, NOAA, Research Triangle Park, N.C., on assignment to Environmental Protection Agency, Region IV, Atlanta, Ga. 30309.

When fuel factors are larger than 120, ventilation requirements can be computed directly with the equations:

$$\text{Backfire } V \geq 100\ F$$
$$\text{Head fire } V \geq 200\ F$$

A fire should be planned so that its rate of smoke production is consistent with a predicted afternoon ventilation factor. A 20,000 square meter per second ventilation disperses twice the smoke that a 10,000 square meter per second ventilation does. However, smoke production depends upon the type of fire, as well as the amount of fuel. A typical backfire in a southern forest emits an average of 40 pounds of particulates per ton of fuel (Ward and others 1974). A typical head fire will emit approximately twice that amount.

FIRE LENGTH

Fire length dramatically affects smoke concentration. Smoke from fires whose crosswind length is 20 chains or less is dispersed better horizontally than smoke from larger fires. Figure 2 applies to fires 25 chains or more from flank to flank; however, these results can be applied to shorter fires by multiplying the observed ventilation by a correction factor. Appropriate correction factors for various fire lengths and times of day are:

Fire length (Chains)	Correction factor (Daytime)	(Nighttime)
5	4.0	2.0
6	3.4	1.7
7	3.0	1.5
8	2.6	1.3
9	2.3	1.1
10	2.0	1.0
15	1.5	1.0
20	1.3	1.0
>25	1.0	1.0

Consider a backfire 10 chains long with a fuel factor of 40. If the ventilation is 3,000, figure 2 indicates that this fire is unacceptable. By applying the correction factor for a 10-chain fire, ventilation is adjusted to 6,000. Thus, 10-chain fires are acceptable during ventilations that make a 25-chain fire unacceptable.

Minimum spacing between fires depends upon the amount of spreading smoke will accomplish and the fire length. Small backfires, 20 chains and under from flank to flank, should not be burned within 60 chains (0.75 mile) of each other. Fires larger than 20 chains flank to flank should not be burned within 100 chains (1.25 miles) of each other. For example, the correction factor for small fires can be applied to two fires burning simultaneously if they are separated by 60 or more chains.

EXAMPLES

Fifty percent of the fuel on a 15-acre plot (10 chains deep by 15 chains long) containing 10 tons of fuel per acre is to be burned. The plot can be burned in 2 hours with five strip backfires. The spread rate should be computed as if there were a single fire:

10 chains per 2 hours = 5 chains per hour.

Available fuel weight is 5 tons per acre (in this case one-half the total fuel weight) and the fuel factor (F) is 25 tons-chains per acre-hour. This fuel factor requires a minimum ventilation of 2,500 square meters per second (fig. 2). Communication with the National Weather Service reveals that the mixing height is 1,000 meters with an average windspeed through that height of 5 meters per second. Ventilation is 5,000 square meters per second, which is sufficient.

If the plot can be burned in 0.5 hour using one strip-head fire, spread rate is quadrupled (10 chains per 0.5 hour = 20 chains per hour). Therefore, the fuel factor is four times the previous value. A fuel factor of 100 in a head fire situation requires a ventilation factor of 20,000 or more (fig. 2). If flank-to-flank fire length is 15 chains, a ventilation of 13,400 (1.5 × 13,400 = 20,100) will satisfy our air quality requirements, but the observed ventilation of 5,000 (1.5 × 5,000 = 7,500) is insufficient.

SUMMARY

Prescribed burning requires critical decisions from initial planning through completion of the burn. An additional restraint that depends on fuel and atmospheric conditions is offered here to preclude air quality incidents. The atmosphere's natural ability to disperse smoke from a prescribed fire will not be exceeded if there are no pollution warnings, alerts, or episodes expected and if answers to the following five questions are positive:

(1) Will relative humidity be 70 percent or less?

(2) Will visibility be 5 miles or more?

(3) Will downwind distance to a smoke-sensitive area be more than 40 chains (0.5 mile)?

(4) Will mixing height be at least 500 meters, with a transport windspeed of at least 4 meters per second?

(5) Will ventilation be 100 or more (200 for head fires) times larger than the fuel factor?

Negative responses to any of the above questions is a necessary and sufficient reason for not burning.

Recommendations made in this paper are based upon conservative assumptions and development. This aid is a simple method whose application will preclude air quality incidents. Components in the original development may be improved; therefore, the author invites user comment on the aid's applicability in various fire situations throughout the South.

LITERATURE CITED

Brender, Ernst V., and Hugh E. Mobley
1974. Regulations on prescribed burning and air quality. For. Farmer 33(4):10, 12.

Craig, D. A.
1973. Environmental regulations and laws. For. Farmer Man. 32(6):42-47.

Environmental Protection Agency
1971. National primary and secondary ambient air quality standards. Fed. Regist. 36: 8186-8201.

Fritschen, Leo, Harley Bovee, Konrad Buettner, and others
1970. Slash fire atmospheric pollution. USDA For. Serv. Res. Pap. PNW-97, 42 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Gross, Edward
1970. The national air pollution forecast program. U.S. Dep. Commer., ESSA Tech. Memo. WBTM NMC 47, 28 p.

Holzworth, George C.
1972. Mixing heights, wind speeds, and potential for urban air pollution throughout the contiguous United States. U.S. EPA Air Programs Publ. AP-101, 118 p.

Hough, Walter A.
1968. Fuel consumption and fire behavior of hazard reduction burns. U.S.D.A. For. Serv. Res. Pap. SE-36, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

Middleton, W. E. K.
1968. Vision through the atmosphere. Univ. Toronto Press, 250 p.

Mobley, Hugh E., Ernst V. Brender, and Dansy T. Williams
1975. Preview of smoke management guidelines. For. Farmer 34(5):90-92.

Murphy, James L., Leo J. Fritschen, and Owen P. Cramer
1970. Research looks at air quality and forest burning. J. For. 68:530-535.

Pharo, James A., and Charles A. Hauck
1975. Smoke dispersion model for prescribed burning. USDA For. Serv. Res. Note SE-220, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

Sackett, Stephen S.
1975. Scheduling prescribed burns for hazard reduction in the Southeast. J. For. 73: 143-147.

Thuiller, Richard H., and James S. Sandberg
1972. Development of a meteorologically controlled agricultural burning program. Bull. Am. Meteorol. Soc. 52(12):1193-1200.

Wade, Dale D.
1969. Estimating slash quantity from standing loblolly pine. USDA For. Serv. Res. Note SE-125, 4 p. Southeast. For. Exp. Stn., Asheville, N.C.

Ward, Darold E., Ernest R. Elliott, Charles K. McMahon, and Dale D. Wade
1974. Particulate source-strength determination for low-intensity prescribed fires. Spec. Conf. Control Technol. Agric. Pollut. Proc. 1974:39-54.

Pharo, James A.

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With the method presented, southern forest managers can decide when a prescribed burn is unlikely to create enough particulate to exceed air quality standards.

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USDA Forest Service Research Paper SE-153 June 1976

Slash, Loblolly, Longleaf, and Sonderegger Pines 20 Years after Planting on Leon Sand in Northeastern Florida

by

Lawrence P. Wilhite

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Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Slash, Loblolly, Longleaf, and Sonderegger Pines 20 Years after Planting on Leon Sand in Northeastern Florida

by

Lawrence P. Wilhite, Silviculturist
Olustee, Florida

Abstract.--Twenty years after planting on disk-harrowed Leon fine sand, slash pine ranked first in height and volume, and shared highest survival with longleaf pine. It therefore appears to be the best choice for short rotations. Loblolly pine ranked second in height and volume, but its height growth rate, after a high peak, declined so rapidly that its suitability for this site is questionable. Longleaf ranked third in height and volume, but it might have potential for long rotations because its height growth rate is declining more slowly than that of slash or loblolly. Sonderegger pine ranked last in height, survival, and volume.

Keywords: Pinus elliottii, Pinus taeda, Pinus palustris, Pinus xsondereggeri, plantations.

Longleaf pine (Pinus palustris Mill.) was the predominant tree species in the virgin and second-growth forests of northeastern Florida and southeastern Georgia. Slash pine (P. elliottii Engelm. var. elliottii) was generally confined to the margins of the many cypress-hardwood swamps that dot this flatwoods area. Loblolly pine (P. taeda L.) grew along major streams and infrequently on swamp margins. A very few Sonderegger pines (P. xsondereggeri H. H. Chapm.), the natural hybrid between longleaf and loblolly, also grew in the flatwoods.

When second-growth stands of the flatwoods are harvested and replanted, slash pine is almost invariably chosen, because it usually has higher planting survival than longleaf and faster growth rate, at least during the early years. This extensive planting of slash pine, plus the invasion of former longleaf sites by slash since the advent of fire protection during the 1930's, is tending to convert the commercial pinelands of the flatwoods to a monoculture of slash pine.

A monoculture is more vulnerable to calamities, such as insect or disease outbreaks, than is a mixture of stands of different species. To determine if loblolly, longleaf, or Sonderegger pines might be productive enough on flatwoods sites to offer an alternative to slash pine monoculture, a study was initiated in December of 1953 on the Olustee Experimental Forest in Baker County, Florida.

An area of Leon fine sand, which is an Aeric Haplaquod and the most prevalent soil type in the flatwoods, was chosen for the study. Six years before planting, the virgin and second-growth longleaf stumps had been bulldozed from this imperfectly drained area. Soon thereafter, it was scarified several times with an agricultural disk harrow. The stems of saw-palmetto (Serenoa repens (Bartr.) Small) were raked from the area to ensure that this hard-to-kill species would not resprout. By the time of planting, the vegetative cover of the area was mostly chalky bluestem (Andropogon capillipes Nash) and other grasses.

The planting stock was raised at the Florida Division of Forestry nursery in Baker County. Seed for the slash pine stock was collected in southern Georgia. The loblolly seed was collected in southern or central Georgia. Seed source of the longleaf is unknown. The Sonderegger seedlings were natural hybrids scattered throughout the longleaf nursery beds, and were identified by their early initiation of height growth.

The 1-year-old seedlings were dibble planted in December 1953 at 8- by 8-foot spacing. Ten rows of 10 planting positions comprise a taxon plot; the inner 8 rows of 8 positions comprise the measurement plot. Plots are replicated four times in a randomized block design.

Survival and growth were measured 0, 1, 3, 5, 8, 10, 15, and 20 years after planting. Plot averages at 20 years were subjected to a standard analysis of variance, plus Scheffé's test,[1] to determine differences among taxa that were significant at the 5-percent level of probability.

SURVIVAL

One year after planting, longleaf pine had the highest survival, followed by slash, Sonderegger, and loblolly (fig. 1). In reporting on the early years of this study, Hoekstra suggested that the poor first-year survival of loblolly was due to drought, plus a heavy attack of Nantucket pine tip moth (Rhyacionia frustrana (Comstock).[2] It should be noted that loblolly had higher survival than slash when planted on the Olustee Experimental Forest in 1958 and 1972, which were both years of near-normal precipitation. Tip moth attacks on loblolly were light in 1958 and heavy in 1972 (unpublished data on file at the Olustee Experimental Forest).

After the first year, Sonderegger suffered more mortality than the other taxa. Most of this mortality was from a dieback of unknown cause. Hoekstra reported that 77 percent of the Sonderegger surviving at 3 years had dead tops. Some of these afflicted trees survived, but they developed stem crooks where lateral branches assumed dominance.

Longleaf has also suffered considerable mortality since the first year. Most of this was due to a slow succumbing of grass-stage seedlings to shading, brownspot needle blight (Scirrhia acicola (Dearn.) Sigg.), or pine webworm (Tetralopha robustella Zell.).

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[1]Scheffé, H. 1953. A method for judging all contrasts in the analysis of variance. Biometrika 40:87-104.

[2]Hoekstra, P. E. 1957. A case study of species comparison on flatwoods soil. South. Lumberman 195(2441):158-159.

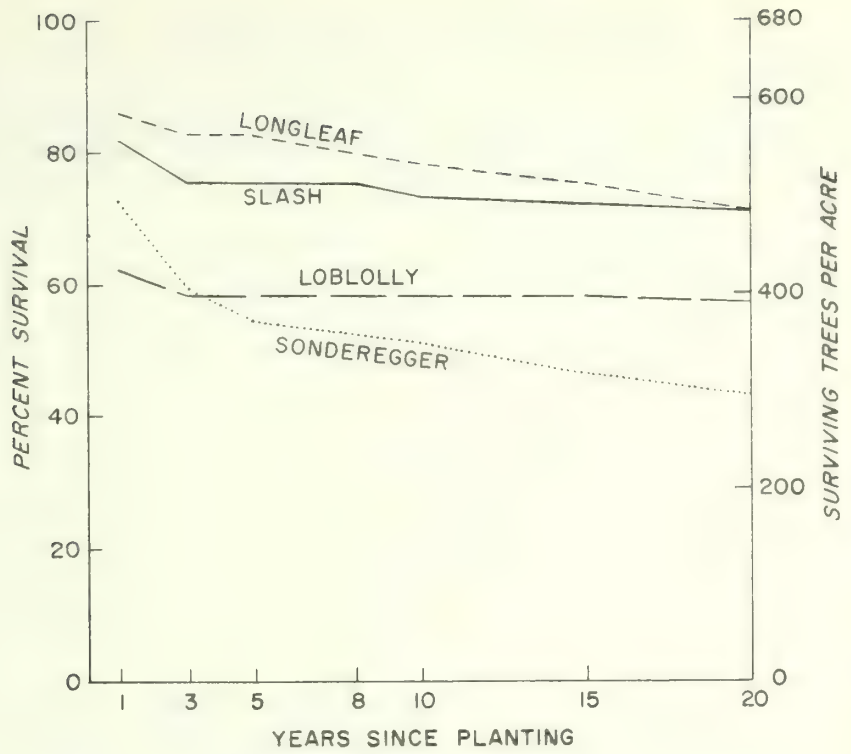

Figure 1.--Percent survival and number of survivors per acre.

Fusiform rust (caused by Cronartium fusiforme Hedg. & Hunt) killed few trees in any taxa. Longleaf, as usual, had fewer galls than loblolly or slash.[3] Based on number of trees planted, percentages lost to, or surviving with, stem galls were:

	Lost to stem gall between third and twentieth years	Surviving with stem galls at twentieth year
Slash	3	6
Loblolly	1	5
Longleaf	1	2
Sonderegger	1	2

Slash and loblolly suffered less mortality than longleaf and Sonderegger after the first year. Consequently, by the twentieth year, slash shared highest survival with longleaf, and loblolly had replaced Sonderegger for third highest survival (fig. 1). At 20 years, both slash and longleaf had significantly higher survival than Sonderegger. No other differences in survival among taxa were significant.

[3]Czabator, F. J. 1971. Fusiform rust of southern pines--a critical review. U.S. For. Serv. Res. Pap. SO-65, 39 p. South. For. Exp. Stn., New Orleans, La.

HEIGHT GROWTH

Slash pine grew more slowly in height than loblolly for the first several years, but grew faster thereafter to become the tallest of the four taxa by the twentieth year (fig. 2). This result probably should not be dismissed as simply

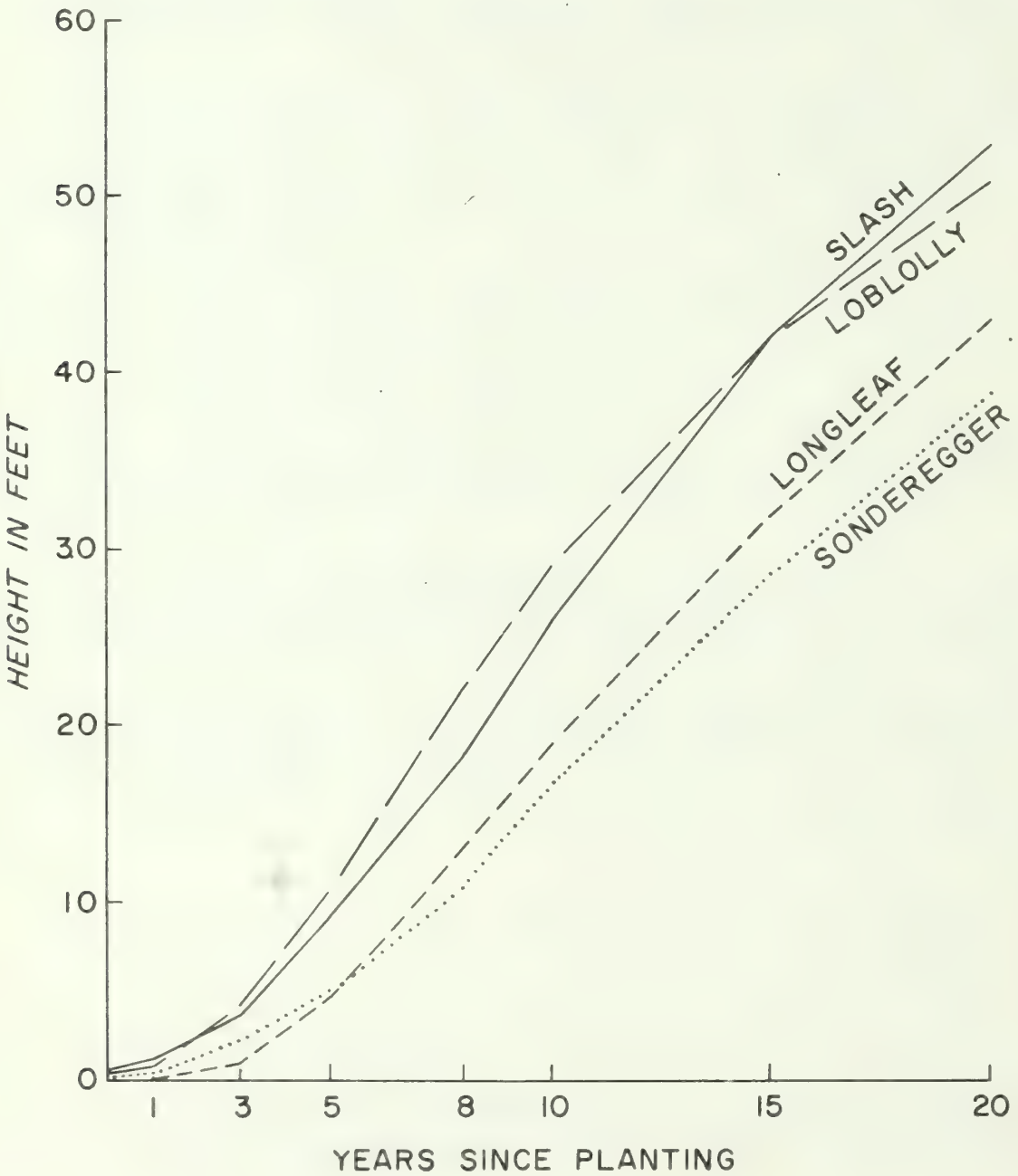

Figure 2.--Average height growth of dominants and codominants. Crown class determinations were made 20 years after planting, at which time 71 percent of the surviving slash, 64 percent of the loblolly, 81 percent of the longleaf, and 57 percent of the Sonderegger were classed as dominants or codominants.

an oddity of this study, for unpublished results from the above-mentioned 1958 planting of loblolly and slash show similar growth trends on a well-drained, an imperfectly drained, and a poorly drained flatwoods site. Longleaf, after coming out of the grass stage, outgrew Sonderegger to become the third tallest taxon.

At 20 years, average height of the dominants and codominants was 53 feet for slash, 51 for loblolly, 43 for longleaf, and 39 for Sonderegger. Slash was significantly taller than longleaf or Sonderegger, and loblolly was significantly taller than Sonderegger. No other height differences among taxa were statistically significant.

Barring drastic changes in height growth patterns, the ranking of site indices (base age 25 years) should follow the same ranking as heights at 20 years. The growth curves in figure 2 suggest that site index will be about 60 feet for slash, a few feet less than 60 for loblolly, about 50 feet for longleaf, and a few feet less than 50 for Sonderegger.

Height rankings might change after age 25. Although longleaf had a lower peak in growth rate than slash or loblolly, it had a slower decline in growth rate thereafter, growing exactly as fast as slash and faster than loblolly between 15 and 20 years (fig. 3). If these growth trends continue, longleaf will compare more favorably with slash and loblolly on a long rotation.

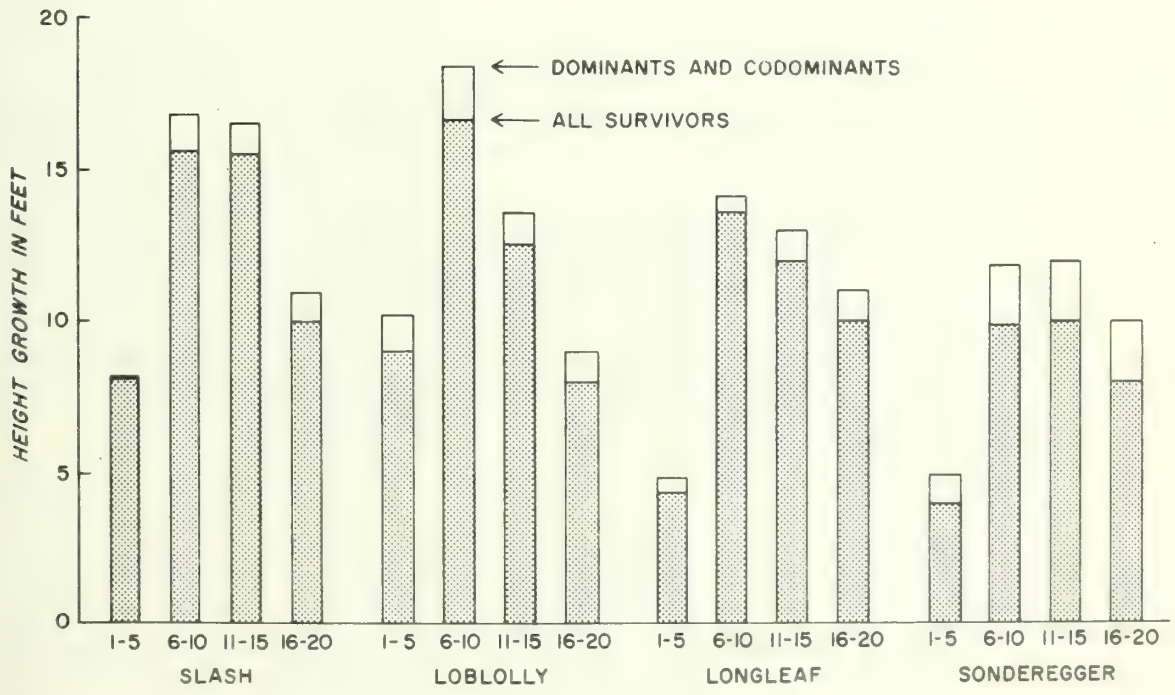

Figure 3.--Average height growth of the twentieth-year survivors by 5-year increments.

DIAMETER AND BASAL AREA GROWTH

Loblolly lost its height lead to slash, but maintained its d.b.h. (diameter at breast height) advantage through the twentieth year. Similarly, Sonderegger grew more slowly in height but faster in diameter than longleaf (fig. 4). These diameter "advantages" probably are of little consequence, for they are at least partly due to lower survival, and hence lesser competition among survivors, in the loblolly and Sonderegger plots.

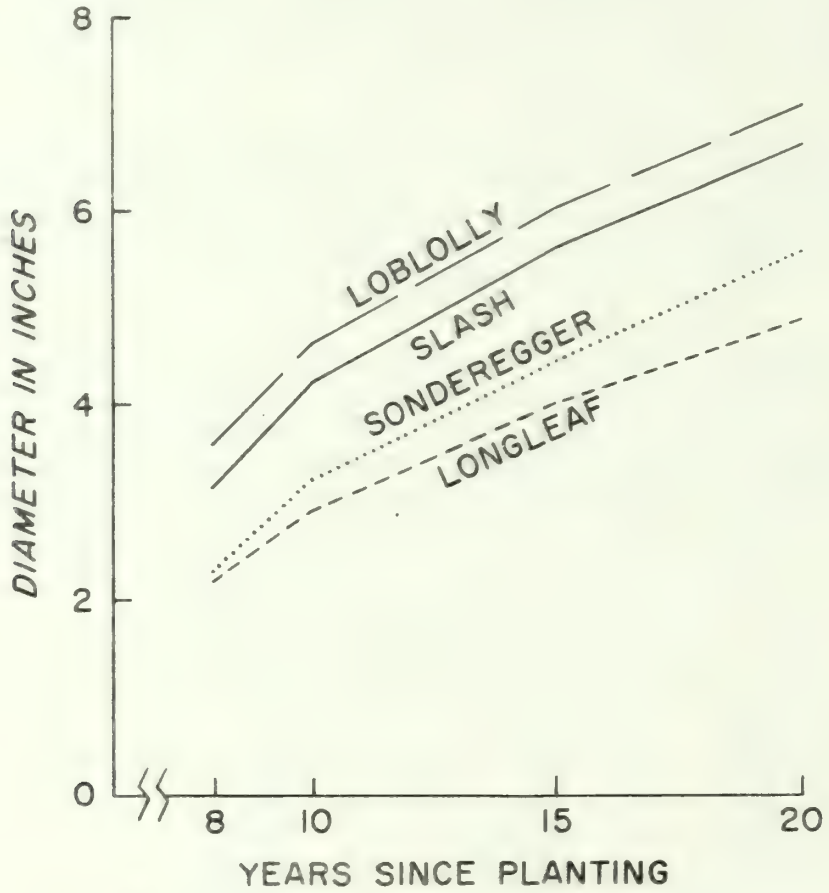

Figure 4.--Average diameter at breast height, based on the tree of average basal area for each taxon. Only trees taller than breast height at the year of measurement and destined to survive to 20 years were used in the computations.

Computing basal area per acre, which reflects both growth and survival, produces a more realistic ranking among the taxa. Since the eighth year after planting, slash has increased its advantage in basal area over loblolly, which in turn has increased its advantage over longleaf, which has increased its advantage over Sonderegger (fig. 5). At 20 years, basal area per acre was 116 square feet for slash, 103 for loblolly, 63 for longleaf, and 51 for Sonderegger. Both slash and loblolly had significantly more basal area per acre than did longleaf or Sonderegger. No other differences in basal area were statistically significant.

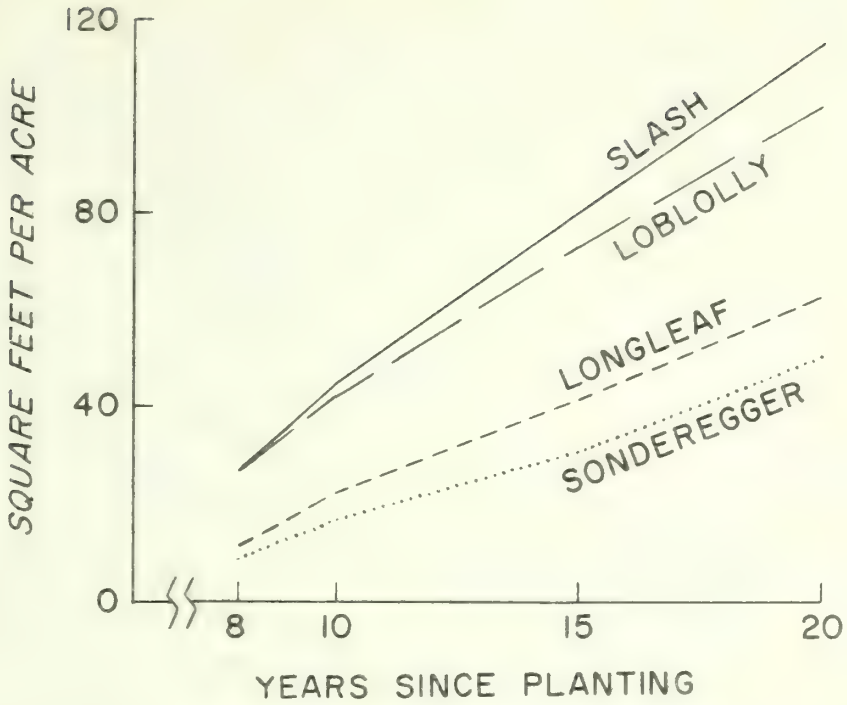

Figure 5.--Basal area growth per acre. Only trees destined to survive to 20 years were used in the comparison.

VOLUME YIELD

Cubic-foot volumes outside bark to a 3.0-inch-diameter top for all stems 3.6 inches d.b.h. and larger were determined, and then converted to cords by assuming 92 cubic feet per cord. Twenty years after planting, yields per acre were 30 cords for slash, 25 for loblolly, 14 for longleaf, and 10 for Sonderegger (fig. 6).

The equations employed for loblolly[4] and slash[5] determine volume to a 0.5-foot stump, whereas the equation for longleaf and Sonderegger[6] determines volume to a 0.2-foot stump. Despite this slight advantage to longleaf and Sonderegger, they each had significantly less volume than did slash or loblolly. No other differences in volume were statistically significant.

Twenty years is probably younger than optimum rotation age for any of the taxa in this study, so the possibility for ingrowth into the merchantable pulpwood class should be mentioned. At 20 years, 58 longleaf, 35 Sonderegger, 16 loblolly, and 3 slash stems per acre were in the 2.6- to 3.5-inch d.b.h. class.

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[4] Bailey, R. L., and J. L. Clutter. 1970. Volume tables for old-field loblolly pine plantations in the Georgia Piedmont. Ga. For. Res. Counc. Rep. 22, Ser. 2, 4 p.

[5] Bennett, F. A., C. E. McGee, and J. L. Clutter. 1959. Yield of old-field slash pine plantations. USDA For. Serv. Stn. Pap. 107, 19 p., Southeast. For. Exp. Stn., Asheville, N.C.

[6] The longleaf equation, Volume = $-0.21766727 + 0.0027880456(D^2)H$, where D = diameter in inches at breast height, and H = total height in feet, has not been published heretofore. It is presented here with the permission of its developer, Robert M. Farrar, Silviculturist, Southern Forest Experiment Station, U.S. Forest Service. This equation was also used to estimate the volume of Sonderegger, for no volume equation exists for sonderegger, and, in this study, it appeared to most resemble the longleaf in stem form.

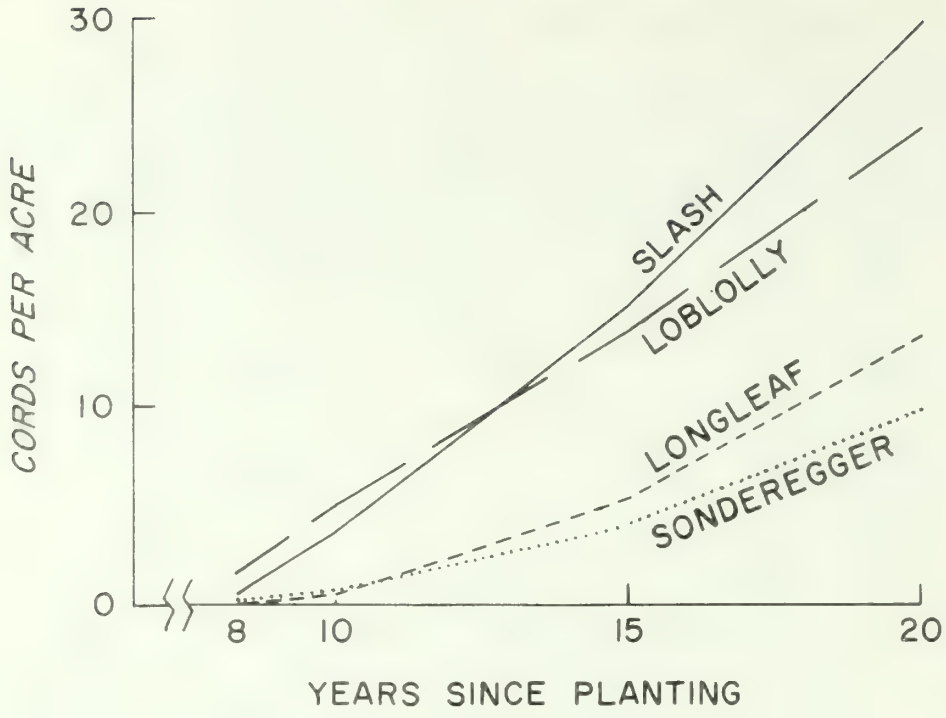

Figure 6.--Yield in merchantable volume of all trees larger than 3.5 inches in diameter at breast height. Only trees destined to survive to 20 years were used in the computations.

Thus, a few more longleaf and Sonderegger than loblolly and slash should enter the merchantable class between ages 20 and 25 or 30 years.

DISCUSSION

At 20 years, slash pine was the tallest of the four taxa, had the greatest merchantable volume, and shared highest survival with longleaf pine. Thus, slash appears to be the best choice on this site for pulpwood rotations of about 25 years.

Loblolly ranked second in height and volume and third in survival at 20 years. Its poor ranking in survival probably should be discounted, because it has had better survival in other studies, and, of course, with better survival, the volume of loblolly would have been closer to that of slash. However, the rapid decline in height growth rate of loblolly between 10 and 20 years makes its suitability for this site questionable.

Longleaf ranked a poor third in height and volume at 20 years. However, it might eventually prove to be a good choice for long rotations for sawtimber, poles, and peeler logs, because of its resistance to fusiform rust, and because, between ages 15 and 20 years, it grew as fast in height as slash, and faster than loblolly.

Sonderegger ranked last in height, survival, and volume at 20 years, and thus seems unsuited to this site.

Wilhite, Lawrence P.
1976. Slash, loblolly, longleaf, and Sonderegger pines 20 years after planting on Leon sand in northeastern Florida. USDA For. Serv. Res. Pap. SE-153, 8 p. Southeast. For. Exp. Stn., Asheville, N.C.

Twenty years after planting on disk-harrowed Leon fine sand, slash pine ranked first in height and volume, and shared highest survival with longleaf pine.

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3.18:SE-154

USDA Forest Service Research Paper SE-154 October 1976

Sampling and Analytical Techniques for an Interim Survey in the South Carolina Lowcountry

by

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and

Robert A. Cathey

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Sampling and Analytical Techniques for an Interim Survey in the South Carolina Lowcountry

by

Richard L. Welch, Resource Analyst

and

Robert A. Cathey, Associate Mensurationist

Abstract.--Remeasurement of 675 permanent sample locations in the South Carolina Lowcountry using modified sampling techniques showed that net growth of pine for the 6 years 1968-1974 was 637.0 million cubic feet while removals were slightly over 390.6 million cubic feet. In 1974, there were 1,533.5 million cubic feet of pine in the area with that portion in sawtimber size amounting to more than 4,987.2 million board feet. Despite a high rate of forest activity in the area over the past 6 years, 56 percent of the stands that remained in forest were in good condition, 14 percent were mature and ready for harvest, and another 14 percent needed some type of intermediate treatment to improve the stand. The remaining 16 percent needed regeneration or stand conversion to make them productive.

Keywords: Forest survey, mensuration.

The Forest Resources Research Work Unit of the Southeastern Forest Experiment Station has been resurveying the forest resources of the five Southeastern States on a cycle of approximately 10 years. Results of past surveys have identified areas where this interval was too long. Extensive land use changes, major increases in resource demand, and widespread natural disturbances have adversely altered both the quantity and condition of forest resources before up-to-date information became available. This paper describes the sampling and analytical techniques used in an interim survey of seven counties in South Carolina referred to as the Lowcountry (fig. 1). These procedures may be applicable in other areas where interim information is needed.

The fourth Forest Survey of South Carolina, completed in 1968, showed that the net annual growth of pine timber exceeded the pine removals by 25 percent in 1967 in the Lowcountry.[1] [2] Furthermore, timber products output studies

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[1]Cost, Noel D. 1968. Forest statistics for the Southern Coastal Plain of South Carolina, 1968. U.S.D.A. For. Serv. Resour. Bull. SE-12, 35 p. Southeast. For. Exp. Stn., Asheville, N.C.

[2]Welch, Richard L. 1968. Forest statistics for the Northern Coastal Plain of South Carolina, 1968. U.S. For. Serv. Resour. Bull. SE-10, 35 p. Southeast. For. Exp. Stn., Asheville, N.C.

Figure 1.--Lowcountry of South Carolina.

in 1970 and 1972 indicated only a modest increase in pine removals. Nevertheless, there was widespread local concern that Lowcountry pine resources were being depleted, and the next resurvey was not scheduled until 1978. The interim survey evolved out of this concern.

The field survey was conducted by the South Carolina State Commission of Forestry in cooperation with the Lowcountry Resource Conservation and Development Project. The Forest Resources Research Work Unit of the Southeastern Forest Experiment Station provided technical assistance in designing the sample and processing the data.

SAMPLING PROCEDURES

The primary objective of the interim survey was to determine changes in the pine timber volume since 1968. Under standard Forest Survey procedures, these changes would have been determined along with those of all components of the inventory. All 1,306 permanent sample locations in the Lowcountry would have been relocated, and a host of detailed measurements and classifications would have been made. Since much of this information was not needed in the interim survey, the standard procedures were modified.

The number of sample locations to be relocated was reduced to 675 by deleting all locations that were not likely to have pine volume. Locations were deleted if they were not on forest land or if they contained no pines in 1968. Pine

volume ingrowth on these sample locations during the 6-year period would have been minimal and would not have appreciably affected the outcome of the study.

The sample design at the remaining sample locations was a 10-point cluster of plots with a basal area factor of 37.5. The cluster was systematically spaced to cover 1 acre. All trees 5.0 inches d.b.h. or larger were measured on variable plots at all 10 points, and trees 1.0 inch to 4.9 inches d.b.h. were measured on a plot with a fixed radius of 6.8 feet at the first three points. All the measurements were recorded on a sample record so that remeasurement would be possible.

In standard surveys, all surviving trees in the 10-point clusters are remeasured, all ingrowth trees are measured, and all dead or removed trees are accounted for. The growth on the dead and removed trees is computed by using average annual diameter increments for the area and adjusted average bole length equations. In the limited interim survey, the standard procedures were streamlined considerably. All hardwood trees recorded on the sample record were ignored. This step greatly reduced the cost of the study because 301 sample locations were in oak-pine or hardwood forest types. All trees at the first three points that were less than 5.0 inches d.b.h. were ignored unless they grew to be 5.0 inches or larger. To further streamline the fieldwork, surviving trees were not actually remeasured. Growth on surviving trees was computed in the same way that growth is normally computed for dead or removed trees.

The area description was also kept to a minimum. Normally, an array of information would be collected to describe both the area and the forest condition at each location. In the interim survey, only two pertinent questions were answered: (1) What treatment or disturbance, if any, has taken place since the 1968 survey to create the current forest conditions? (2) What management opportunities are there, if any, to improve timber growth?

FIELD PROCEDURES

The field procedures were to find the old sample location, classify the area, record all dead or removed trees, and measure and record the ingrowth trees. New information was written on a remeasurement record form (fig. 2).

County maps and aerial photographs showing the approximate locations of the samples were available from the 1968 survey. An azimuth and distance from a clearly defined starting point to the location center was on the old sample record. Using this information, all of the samples were relocated.

The area information consisted of location identification, several items needed in processing, and the two area classifications. The location identification information was transferred from the old sample record. The area classifications were the same as those in the 1972 survey of Georgia.[3]

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[3]Knight, Herbert A., and Joe P. McClure. 1974. Georgia's timber, 1972. USDA For. Serv. Resour. Bull. SE-27, 48 p. Southeast. For. Exp. Stn., Asheville, N.C.

STATE	UNIT	COUNTY	LOCATION	LAND USE	PAST TREAT. OR DIST.	TREAT. OR DIST. PERIOD	TREAT. OPPOR.	REMEAS. PERIOD
XX	X	XX	XXX	X	XX	XX	X	XXX
39								

POINT NO.	TREE NO.	SPECIES	HISTORY	OLD D.B.H.	NEW D.B.H.	CUT-MORT. PERIOD	UTILIZ.
X	XX	XXX	X	XXX	XXX	XX	X

LAND USE

1 Forest
2 Nonforest

SPECIES

110 Shortleaf
111 Slash
115 Spruce
121 Longleaf
128 Pond
131 Loblolly

TREE HISTORY

Remeasurement of sample location

1 Live tree recorded on previous survey or live tree tallied on the 10-point cluster.

2 Ingrowth 5.0 inch d.b.h. or larger on smallest fixed plot not recorded on previous survey.

6 Dead tree 5.0 inch d.b.h. or larger recorded as a live tree on previous survey.

8 Tree removed from commercial forest recorded as live tree on previous survey.

Figure 2.--Remeasurement record form.

The first 3 points of the 10-point cluster were always checked for ingrowth pines (trees growing from below 5.0 inches d.b.h. to 5.0 inches or larger). If an ingrowth pine was found, point number, species, and appropriate tree history were recorded, and the new d.b.h. was measured and recorded. No attempt was made to obtain ingrowth mortality or removal data.

All 10 points were checked for mortality and removed trees. If one was found, point number, tree number, species, and old d.b.h. were recorded, along with the appropriate tree history and the approximate period since death or removal. In addition, a utilization class was given to each removed tree. No tree information was recorded for surviving trees.

DATA PROCESSING

The processing procedures consisted of editing the new data; merging the new data with that of 1968; computing new diameters and bole lengths, where needed; computing volumes; and compiling tables.

After the data on the remeasurement records were punched into data cards, extensive computer editing was done to spot omissions, invalid codes, and errors in logic. When the data were found to be free of such errors, they were merged with the historical data from the 1968 survey, and the new diameters and bole lengths were computed.

During the 1968 survey, 3,060 pines in the vicinity of the Lowcountry were remeasured about 10 years after the preceding survey. Average annual radial increment was determined by species and 2-inch-diameter class. These averages were used to estimate diameter growth for all trees needing new diameters. Bole-length equations generated from length measurements on 11,264 trees in the Southeast were used to estimate bole-length increment. The lengths were measured with sectional aluminum poles, as described by McClure.[4] Because the average bole lengths computed from these equations were regional, they were adjusted to gain local sensitivity. This adjustment was done tree by tree, by determining the ratio of the old bole length to a computed old bole length, and then applying the ratio to the new computed bole length.

Both the old and new cubic volumes were computed with standard equations. The cubic-foot volumes were then converted to board feet by using average board foot-cubic foot ratios for all trees that were 9.0 inches d.b.h. or larger.

RESULTS

In 1974, there were 1,533.5 million cubic feet of pine in the area (table 1). The net growth for the 6-year remeasurement period was 637.0 million cubic feet, and the removals amounted to over 390.6 million cubic feet. Although

Table 1.--Changes in volume of pine in South Carolina Lowcountry, 1968 to 1974

Item	All timber	Sawtimber
	M cubic feet	M board feet
Inventory 1968	1,287,210	4,305,897
Period changes:[1]		
Gross growth	673,444	2,232,198
Mortality	36,490	117,760
Net growth	636,954	2,114,438
Removals	390,629	1,433,120
Net change	246,325	681,318
Inventory 1974	1,533,535	4,987,215

[1] Does not include ingrowth mortality or ingrowth removals.

[4] McClure, Joe P. 1968. Sectional aluminum poles improved length measurements in standing trees. U.S.D.A. For. Serv. Res. Note SE-98, 4 p. Southeast. For. Exp. Stn., Asheville, N.C.

Table 4.--Distribution of remeasured sample locations, by treatment opportunity, South Carolina Lowcountry, 1974

Treatment opportunity	Number of locations
Immature stand in good condition	367
Merchantable stand damaged (salvage needed)	1
Mature stand ready for harvest	90
Commercial thinning	63
Precommercial thinning	1
Cleaning, release, or other stand improvement	25
Stand conversion	17
No manageable stand (regeneration needed)	86
Total number of samples	650

random-sampling formula to be 5 percent for the 1968 inventory. Since the 1968 pine sample and ingrowth were completely accounted for, there is no sampling error associated with the estimate of net change.[5]

DISCUSSION

The Lowcountry interim survey provided a reliable up-to-date look at the pine situation, and the results are being used to guide forest management in the area. The study cost approximately $20,000 and took 3 months to complete. Three two-man crews accomplished the fieldwork. The average cost of remeasuring and processing was $30 per sample location, or one-third the cost of a complete remeasurement. Financing for the entire Lowcountry study was arranged by the South Carolina State Commission of Forestry; the Forest Resources Research Work Unit of the Southeastern Forest Experiment Station provided technical assistance and historical records needed for the study.

In addition to the direct benefits of the Lowcountry survey, it also demonstrated that standard remeasurement procedures could be modified to provide a reliable up-to-date look at a particular timber situation at a relatively low cost. At present, there are approximately 40,000 permanent sample locations distributed across all land uses in the Southeast. Although they were intended for use in statewide surveys, they can be used in smaller areas of 1 million acres or more and still yield reliable results. Should it be necessary to conduct interim surveys in the future, the permanent sample locations, the sampling procedures, and the analytical techniques are available.

[5] Spurr, Stephen H. 1952. Forest inventory. 476 p. The Ronald Press Co., New York.

Welch, Richard L., and Robert A. Cathey
1976. Sampling and analytical techniques for an interim survey in the South Carolina Lowcountry. USDA For. Serv. Res. Pap. SE-154, 8 p. Asheville, N.C.

Remeasurement of 675 permanent sample locations in the South Carolina Lowcountry using modified sampling techniques showed that net growth of pine for the 6 years 1968-1974 was 637.0 million cubic feet while removals were slightly over 390.6 million cubic feet.

Keywords: Forest survey, mensuration.

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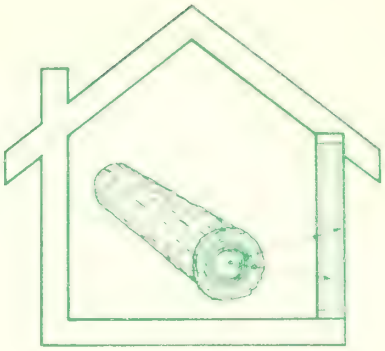

COM-PLY 2 REPORT

PERFORMANCE STANDARDS FOR COMPOSITE STUDS USED IN EXTERIOR WALLS

COOPERATIVE RESEARCH

Note: Revised passages are noted by asterisks on pages 15 and 17.

July 1978

Southeastern Forest Experiment Station
Asheville, North Carolina

PERFORMANCE STANDARDS FOR COMPOSITE STUDS USED IN EXTERIOR WALLS

by

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Southeastern Forest Experiment Station

and

U.S. Department of Housing and Urban Development
Division of Energy, Building Technology
and Standards

PREFACE

This report is one of a series on the possibilities of producing house framing and structural panels with particleboard cores and veneer facings. These COM-PLY or composite materials were designed to be used interchangeably with conventional lumber and plywood in homes. Research on structural framing is present limited to COM-PLY studs but will be extended to include larger members such as floor joists.

In 1973, the home-building industry faced a shortage of lumber and plywood and consequent rising prices. Both industry and government recognized that this situation was not a temporary problem, and that long-range plans for better using the Nation's available forest resources would be necessary.

The USDA Forest Service and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with particleboard and veneer as a way of using not only more of the tree stem, but also using less desirable trees and a greater variety of tree species than would conventional wood products The particleboard which comprises a large portion of the COM-PLY stud is made from ground-up wood that comes from forest residues, mill residues, or low-qualit timber. Thus, such composites could greatly increase the amount of lumber and plywood available for residential construction, our major use of wood, without eroding the Nation's timber supply.

Research on composite wall framing was performed by the Wood Products Research Unit, Southeastern Forest Experiment Station, Athens, Georgia. The American Plywood Association cooperated in these studies by designing and testing composite panel products that are interchangeable with plywood. Both types of products have been incorporated in demonstration houses.

Included in this series will be reports on structural properties, durability dimensional stability, strength, and stiffness of composite studs. Other reports will compare the strength of composite and solid wood studs, suggest performance standards for composite studs, and provide construction details on houses incorporating such studs. Still others will explore the economic feasibility of manufacturing composite studs and panels and estimate the amount and quality of venee available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

CONTENTS

	Page
METHODS OF DEVELOPING PERFORMANCE STANDARDS	2
GENERAL	2
STRUCTURAL STRENGTH AND STIFFNESS	6
DURABILITY	7
DIMENSIONAL STABILITY	8
STRENGTH OF NAILED JOINTS	9
PERFORMANCE STANDARDS FOR COM-PLY STUDS	10
GENERAL	10
STRUCTURAL STRENGTH AND STIFFNESS	12
Standard Level	12
Laboratory Test	12
Determining Acceptability	14
DURABILITY	15
Standard Level	15
Laboratory Test	16
Determining Acceptability	17
DIMENSIONAL STABILITY	17
Standard Level	17
Laboratory Test	18
Determining Acceptability	18
STRENGTH OF NAILED JOINTS	19
Standard Level	19
Laboratory Test	19
Determining Acceptability	21
DISCUSSION	22
RECOMMENDATIONS	22
LITERATURE CITED	23

ACKNOWLEDGMENT

The Forestry Sciences Laboratory, Wood Products Research Unit, acknowledges the valuable assistance and guidance of:

Orville G. Lee, AIA
Howard C. Hilbrand, PE
U.S. Department of Housing and Urban Development

Charles R. Morschauser, Technical Director
Hubert T. Dudley, Quality Control Director
National Particleboard Association

PERFORMANCE STANDARDS FOR COMPOSITE STUDS USED IN EXTERIOR WALLS

Abstract.--This report presents standards for evaluating the strength, stiffness, durability, and dimensional stability of COM-PLY wall studs and the strength of joints made with these studs. The standards set levels of acceptable performance for studs used in residential construction. Test methods for evaluating performance are described in detail. Manufacturers can use these standards to determine if COM-PLY studs they produce are adequate for use in building homes. Building code officials can use the standards for accepting or rejecting COM-PLY studs for use within the code jurisdiction.

KEYWORDS: Stud performance, stud strength, stud durability, stud dimensional stability, wall performance, wall framing.

The U.S. Department of Housing and Urban Development and the USDA Forest Service have performed cooperative research that has led to the development of a new composite lumber product. The new product, called COM-PLY, has potential for significantly increasing the supply of lumber for building homes. Composite lumber requires fewer trees to produce the same amount of lumber than when lumber is produced by conventional sawing practice.

COM-PLY lumber, including the COM-PLY stud, is a structural sandwich construction with a particleboard core placed between layers of solid wood veneer (fig. 1). This report deals with 2 x 4 COM-PLY studs used to frame the exterior walls of single-family homes and light-frame construction (fig. 2). These studs are intended to be used interchangeably with 2 x 4 wall studs of sawn lumber and at the same spacings, but are not intended as general substitutes for 2 x 4 sawn lumber.

Figure 1.--COM-PLY stud used for framing exterior walls of houses.

Figure 2.--COM-PLY studs installed in a house under construction.

Potential manufacturers of COM-PLY studs, building code officials, and builders must be able to determine the strength, stiffness, durability, dimensional stability, and fastening or joint strength of these studs in order to qualify them for safe, acceptable use in building homes. Suggested performance criteria for these properties in COM-PLY studs are presented in this report. With these standards, manufacturers can determine for themselves whether particular wood species and adhesives are satisfactory for stud production.

METHODS OF DEVELOPING PERFORMANCE STANDARDS

GENERAL

Although builders in the United States have used wood studs to frame the walls of houses for over three centuries, no national performance standards exist for wood studs in house construction (Whittemore and others 1948). In building codes, the specifications for size and quality of framing studs have evolved from builders' past methods of construction. In recent years, however, code officials and the housing industry have advocated developing performance standards to replace traditional specification standards. A specification standard requires that components be spaced so many inches apart and be of a particular size and quality. A performance standard requires that components have sufficient strength,

stiffness, durability, and other attributes to perform their intended functions. Specification standards tend to restrict development of new products, because only the materials and sizes specified can be used. Performance standards, on the other hand, allow for a wide range of materials and sizes as long as the product meets the levels of performance set forth by the code.

In developing the performance standards for COM-PLY studs, we collaborated with engineers of the Federal Housing Administration (FHA), U.S. Department of Housing and Urban Development (HUD). Engineers from model building code associations then reviewed our methods of developing these standards. FHA engineers are increasingly concerned about the variation in strength of given building products used in housing. Because such products are often accepted on the basis of average strength values rather than the strength of the weakest element, the structures incorporating them may be unsafe. Thus, the FHA engineers wanted to use formulas that account for variation in the properties of building materials. The formulas we provide use statistical methods to account for variation of such properties as strength, stiffness, durability, and joint strength. The values obtained from these formulas can then be compared with pre-established minimum values for performance and the set of studs accepted or rejected for home building.

Tests indicate that strength and stiffness properties are normally distributed in populations of COM-PLY studs. Using standard analytical statistics for a normal distribution (Dixon and Massey 1969), we can accurately estimate how much the average strength of a sample of COM-PLY studs might vary from the average strength of the entire population from which the sample was drawn. We can also accurately estimate how much the strength of the weakest or strongest stud will vary from the average, or what percentage of the entire population of studs we might expect to lie between specified upper or lower limits of strength. The variation from the average of any sample is measured by a statistic called the standard deviation and is designated by the letter S. Methods of calculating the standard deviation can be found in any standard statistics textbook.

The statistic t, along with the standard deviation S, provides a way of accurately predicting the range of population values. For a sample of N number of studs, the average test strength can be designated as $\bar{x}$. The average strength of the entire population could be higher or lower than the average found by testing a few studs. The lower limit of the average strength of the population can be estimated by the formula:

$$\bar{x} - \frac{t_{\alpha} S}{\sqrt{N}}$$

The letter α indicates the level of significance used in selecting a value of t; in the performance standards to be presented, α has a value of 5 percent. In other words, the value of $\bar{x}$ will not be less than the calculated value unless a 1 in 20 sampling error has been made. The t distribution depends on the degrees of freedom (d.f.) of the sample. For the analyses in this report, d.f. = N - 1. Table 1 lists values of t for $\alpha = 0.05$ at degrees of freedom likely to be encountered in these performance standards.

An example will illustrate how to select a value of $t_{0.05}$. Assume 20 studs were tested. Then N = 20 and there are N - 1 or 19 degrees of freedom. From Table 1 the value of $t_{0.05}$ for d.f. = 19 is 1.73.

Table 1.--Values of the statistic t at various degrees of freedom (d.f.) for $\alpha = 0.05$

d.f.	t	d.f.	t	d.f.	t	d.f.	t	d.f.	t
1	6.31	7	1.89	13	1.77	19	1.73	25	1.71
2	2.92	8	1.86	14	1.76	20	1.72	26	1.71
3	2.35	9	1.83	15	1.75	21	1.72	30	1.70
4	2.13	10	1.81	16	1.75	22	1.72	40	1.68
5	2.01	11	1.80	17	1.74	23	1.71	60	1.67
6	1.94	12	1.78	18	1.73	24	1.71	120	1.66

Another example will illustrate the calculation of the lower limit of the population average. Assume 20 studs were tested and found to have an average ultimate or failure strength, $\bar{x}$, of 101.4 pounds per linear foot of bending load. Assume a standard deviation S of 15.9 pounds per linear foot of bending load. The value of $t_{0.05}$ for d.f. = 19 is 1.73. Substituting the values of $\bar{x}$, t, S and N in the formula for estimating average strengths of the population, one obtains

$$101.4 - \frac{(1.73 \times 15.9)}{\sqrt{20}}$$

or 101.4 - 6.15 pounds per linear foot. In other words, after testing 20 COM-PLY studs we would be 95 percent confident that the true averages of stud strength are not less than 95.2 pounds per linear foot. Thus, our best estimate of the average population strength to use for design is 95.2 pounds per linear foot of bending load.

For a normal distribution of strength properties, 95 percent of the population is likely to be stronger than $\bar{x} - t_{0.05}S$. This is usually referred to as the 5-percent exclusion limit.

The various adjustments of the average test values of the sample can be combined into one expression as follows:

$$\bar{x} - \frac{t_{0.05}S}{\sqrt{N}} - t_{0.05}S$$

The first term of this expression is the average value of some attribute of the test sample, the second term corrects the average sample value to estimate the lower or safe limit of the population average for that attribute, and the third term estimates the 5-percent exclusion limit.

The expression is further modified when used for strength computations, as follows:

$$\left[\bar{x} - \frac{t_{0.05}S}{\sqrt{N}} - t_{0.05}S\right] \quad \frac{F_r}{F_s F_t}$$

where F_r, F_s, and F_t are adjustment factors for load sharing, safety, and duration of load.

Wall studs are usually used in conjunction with several studs in a given frame. When three or more wood studs make up a frame, the load-carrying capacity of an individual stud is in effect increased 15 percent through the benefits of load sharing with adjacent members (NFPA 1973). The term F_r accounts for load

sharing and is used to modify the general expression whenever bending strengths are being evaluated. For this application, the value of F_r is 1.15. For most other strength evaluations such as testing nailed joints, the value of F_r is 1.0.

Without the safety factor F_s, some of the weaker studs or joints might fail when the design load is applied or an accidental overload occurs. A value of 1.5 for the safety factor was selected for these standards. This factor means that 95 percent of the pieces would withstand a 50-percent overload before any failures occur. This figure is a conservative estimate because other parts of the structure such as wall sheathing or interior wall finish contribute some strength that is not accounted for by the methods used.

The factor for duration of load, term F_t, is used to account for the difference between the period the test load was applied and the period the service load, such as wind load, is expected to be applied. In general, wood products can sustain heavier breaking loads for short periods (one second or one minute) than for long periods (several months or years). Laboratory tests to evaluate mechanical strength properties of wood are made in a relatively short time (usually 5 to 20 minutes), whereas service loads may continue for the life of the structure. Therefore, laboratory test values for strength usually are too high and must be adjusted downward to represent conditions under service load. To determine the value for F_t, the factor for duration of the test load is divided by the factor for duration of the service load (Hunt and others 1973; ASTM 1975b). For example, if the average test period is 15 minutes (factor for duration of load, 1.57) and the service load is a one-day wind load (factor for duration of load, 1.33), then the value of F_t is 1.57/1.33 or 1.18.

Values of bending deflection and joint deformation are usually based on average values rather than on minimum values as for strength. The greatest average deflection or deformation would be of the most concern to a designer. The greatest average deflection or deformation of a population can be estimated from test data by the following expression:

$$\bar{d} + \frac{t_{0.05} S}{\sqrt{N}}$$

In this expression, $\bar{d}$ is the average deflection or deformation in a test sample of N number of specimens. The other terms have been previously defined. A plus sign rather than a minus sign is used in the expression because it is the greatest average population value for deflection that is to be estimated, not the least.

An example will illustrate how to use the expression. Population deflections or deformations can be estimated as follows for a sample of 20 test studs with an average test bending deflection, $\bar{d}$, of 0.284 inch and a standard deviation of 0.037 inch under a bending load of 30 pounds per linear foot:

$$\bar{d} + \frac{t_{0.05} S}{\sqrt{N}} = 0.284 + \frac{1.73\ (0.037)}{\sqrt{20}} = 0.298 \text{ inch}$$

Thus, there is one chance in 20 that the average deflection of the population would exceed 0.298 inch.

In general, the method proposed here for evaluating strength and stiffness is to test a sample of COM-PLY studs for these properties according to definite procedures and then adjust the values to account for variation in the entire

population and other factors, as outlined above. The population of studs can then be accepted or rejected for home building according to whether the adjusted values equal or exceed performance standards previously judged acceptable by building code, FHA, and other officials, as discussed in the following sections.

STRUCTURAL STRENGTH AND STIFFNESS

Conventional 2 x 4 studs of sawn lumber are currently spaced in exterior walls at either 16 or 24 inches. Generally, the major model building codes and the FHA minimum property standards require a 16-inch spacing for such studs in the lower story of two-story houses because the exterior walls support floor, roof, and ceiling loads. On the other hand, 24-inch stud spacing is permitted in the upper story of two-story houses or in the exterior walls of one-story houses because the only contributing downward load is from the roof and ceiling.

The wall stud is the structural member that must support axial compressive end loads as a column from roof and floor loads. In addition, a stud must resist transverse bending resulting from wind pressures acting inwardly on the exterior wall surface. The amount of downward axial compressive load depends on the size (primarily the width) of the house, number of stories, and the types of live and dead loads on the structure. Design wind pressures vary according to geographic location.

FHA engineers suggested the following house characteristics and typical loadings to help establish acceptable performance levels for exterior wall studs supporting axial and bending loads:

Design house width	30 feet
Length of roof eave overhangs	2 feet
Live and dead roof and ceiling loads acting on horizontal projection	35 pounds per square foot
Live and dead load from second-story floor	40 pounds per square foot
Wind load for strength computations	20 pounds per square foot
Wind load for deflection computations	15 pounds per square foot

For the two typical stud spacings, the resulting loads for strength computations are as follows:

	Axial load	Bending load
	Pounds	Pounds per linear foot
Studs spaced 24 inches o.c. (1-story house or upper story of 2-story house)	1,190	40.0
Studs spaced 16 inches o.c. (lower story of 2-story house)	1,270	26.7

The most critical spacing is 24 inches. For a 24-inch spacing the axial load is 7 percent less than for the 16-inch spacing, but the bending load is 50 percent greater. In this report the acceptable design loads used for strength performance are 1,190 pounds for axial compression and 40 pounds per linear foot for bending (2-foot spacing x 20 pounds per square foot).

For bending deflection the acceptable design loads are 1,190 pounds for axial compression and 30 pounds per linear foot for bending (2-foot spacing x 15 pounds per square foot). The maximum allowable deflection of the stud under such loads is the test span (90 inches) divided by 240 or 0.375 inch. FHA has found that the deflection ratio of 240 represents the maximum allowable deflection for studs in housing.

The test method to be described uses two concentrated bending loads acting at the quarter points of the test span rather than a uniformly distributed bending load. The former method is simpler to set up in most laboratories that use universal testing machines for applying loads. A beam bent with two concentrated loads located at the quarter points will deflect more at mid-span with the same amount of applied load than a beam bent with a uniformly distributed load. Since two concentrated loads are used in this Performance Standard, the increased deflection must be accounted for. A uniformly distributed bending load of 30 pounds per linear foot will place 225 pounds on a 7.5-foot test span and deflect the beam 0.375 inch. However, two concentrated bending loads of 225 pounds (112.5 pounds each) on a 7.5-foot test span will deflect the same beam 0.412 inch. These minimum levels of structural performance have apparently been satisfactory for housing insured by FHA. After reviewing the proposed criteria, officials with Building Officials and Code Administrators International and Southern Building Code Congress International also agreed that these minimum levels are satisfactory.

DURABILITY

As with solid wood studs, COM-PLY studs must be durable enough to withstand outdoor weathering prior to installation and changes in both temperature and humidity during and after installation. Of particular concern is the durability of the resin bond in the particleboard core and that of the adhesive bond used to laminate the veneers to each other and to the core.

In setting a performance standard, we had to decide how much weathering would be sufficient to test durability and how much weakening or distortion could be permitted as a result of such weathering. To arrive at a test of durability, we collaborated with scientists and engineers from the National Particleboard Association, the Forest Products Laboratory, and the Department of HUD. The following points were considered in devising the test:

(1) Duff (1972) has shown that the moisture changes within conventional studs in wall cavities are not nearly as great as changes within studs exposed to outside weathering. Thus, the durability of COM-PLY studs would probably be far less affected by moisture changes after installation in a house than by such changes prior to installation.

(2) The most severe weathering exposure that a stud should have to withstand would be one year of unprotected, direct exposure to weathering. This exposure should be endured without a significant loss of strength or stiffness. One year of exterior weathering was selected because it represents a probable maximum period to which builders would expose a framed-in house without roof protection. The consensus was that this would be a reasonable test of durability. However, tests requiring a period of one year are impractical. Manufacturers and building officials prefer a test of durability which requires a much shorter time, such as one or two weeks.

(3) There is no known laboratory accelerated test, equivalent to one year's outdoor weathering, that can determine the durability of COM-PLY studs. However, one test method, the ASTM D 1037 accelerated aging test (ASTM 1975a), has demonstrated good correlation with long-term (several years') outdoor

weathering of particleboard products (Hann and others 1962). This test method, which involves wetting and drying at high temperatures, has proven satisfactory for determining the long-term durability of exterior particleboard.

Even though COM-PLY studs were designed to withstand only one year of outdoor weathering, we used this test to evaluate them because it was the only standard testing procedure for exterior particleboard. Since the exposure test is more severe than one year's outdoor weathering, COM-PLY studs that pass the D 1037 exposure test will certainly be durable enough to use in building houses.

A modification of the ASTM D 1037 test was selected as an interim method of evaluating the durability of COM-PLY studs. The freezing cycle of the D 1037 test method was eliminated, since freezing apparently has little effect on durability compared to the effect of wetting and drying at high temperatures.

The collaborators decided that, after the modified test exposure, COM-PLY studs should retain 50 percent of their unexposed strength and should not have an increase in unexposed deflection of more than 100 percent, as determined by the structural test for strength and stiffness.

The Wood Products Research Unit at Athens, Georgia, is performing long-term outdoor exposure tests of COM-PLY studs (fig. 3). These tests may show that the acceptable levels of durability for COM-PLY studs can be raised. If so, this standard will be changed. Perhaps these tests will also provide guidance in developing a less severe laboratory test for evaluating the durability of the laminating adhesives and particleboard resin binders in COM-PLY studs.

DIMENSIONAL STABILITY

Wood products tend to change dimension with changes in moisture content. When the moisture content of COM-PLY studs increases during outdoor weathering, the studs may warp or increase in size (thickness, width or length). The amount of these changes is determined by the dimensional stability of the studs. Warpage is any variation from a true plane surface. For studs, the most crucial types of warpage are crook, bow, and twist as typically defined in lumber-grading rules. Too much warpage or change in size may make studs unsuitable for home building.

To formulate a method for evaluating dimensional stability, we collaborated with the same advisers who helped develop the test on durability. The following points were considered in devising the test:

(1) The most severe swelling and warping results from soaking dry studs in water until each stud is essentially saturated and then redrying the studs to a relatively low moisture content. Heebink and Hefty (1969) have demonstrated that the greatest swelling of particleboard occurs during the first cycle of water soaking. They also showed that the greatest increase in thickness occurs during the first 24 hours of testing particleboards without wax. On the basis of this study and recommendations by the National Particleboard Association, we decided to evaluate dimensional stability by preconditioning the studs to a moisture content of 10 $\pm$ 2 percent, soaking them for 24 hours, and then measuring warpage and size change.

(2) The percentage increase in thickness (1-1/2-inch dimension), width (3-1/2-inch dimension), and length after soaking in water should not be greater than corresponding changes for solid wood studs. This limit is essential for width and length because substantial changes in these dimensions could crack or distort the finished wall. Swelling in thickness is less critical because such swelling occurs in the wall cavity and probably would not affect appearance of the structure. Similarly, warpage of COM-PLY studs should not exceed what has been found acceptable for sawn lumber studs.

Figure 3.--COM-PLY studs on outdoor exposure test fence at Athens, Georgia.

The acceptable limits of dimensional change and warpage after water soaking, as determined by tests on sawn lumber studs, are listed in the performance standard for dimensional stability. Studies by Duff (in press) show that critical changes such as warpage and swelling across the width are much less for COM-PLY studs than for sawn lumber studs.

STRENGTH OF NAILED JOINTS

Several types of nailed joints are typically used for fastening studs into place and for fastening other building components to studs. Studs can be end-nailed or toe-nailed into place; sheet materials are faced-nailed onto the 1-1/2-inch side of the stud. These joints can be loaded laterally or in direct withdrawal. At the Forestry Sciences Laboratory, Walker (in press) showed that the strength of nailed joints made with COM-PLY studs is usually equal to or greater than that of similar joints made with spruce 2 x 4's.

Kuenzi (1955) and Wilkinson (1972) showed that lateral loads on nails joining a wood member to another wood or nonwood member induce the greatest bearing stress on the wood at the interface of the joint. Therefore, the lateral load capacity of nails driven into the narrow face of COM-PLY studs will be essentially

the same as the lateral load strength of a solid wood stud of the same species as the veneer on the COM-PLY stud. Walker (in press) has confirmed that COM-PLY stud made with southern pine veneer can sustain greater lateral loads on face nails tha can spruce studs.

COM-PLY studs need not be tested for strength of face-nailed joints in order to qualify for use in residential construction. First, builders seldom use face nails loaded in withdrawal. Second, standards such as the National Design Specification for Stress Grade Lumber and its Fastenings (NFPA 1973) emphasize that structural designs should not use constructions with face nails loaded in withdraw

To a great extent, the strength of joints between COM-PLY studs and the plate depends on properties of the particleboard. If the particleboard core has a medi density (35 pounds per cubic foot or greater) and a reasonably high internal bond strength (85 pounds per square inch or greater), there is apparently little need for requiring performance evaluation of nailed joints with COM-PLY studs; such joints will be stronger than those made with some of the low-density species now used for studs. However, for particleboards with a density lower than 35 pounds per cubic foot, an internal bond lower than 85 pounds per square inch, or a partic geometry consisting of flakes that tend to split when nailed parallel to the flake plane, there should be a method for evaluating joint strength.

In order to qualify COM-PLY studs for acceptance in residential construction the standards require testing only end- and toe-nailed stud-to-plate joints for lateral load capacity. ASTM D 1761-74 (ASTM 1975c) and Scholten and Molander (19 define methods for physical tests of nailing. For the most part, we adopted thes methods. However, we also calculated allowable strength and deformation of naile joints on the basis of the same statistical formulas used to compute allowable strength and deflection of single COM-PLY studs. In the formula for nailed joint however, F_r has a value of one because nailed joints receive no credit for load sharing.

The acceptable level of lateral strength for nailed joints between studs and plates is 160 pounds. This amount was computed by multiplying a wind load of 20 pounds per square foot by a stud spacing of 2 feet by a stud length of 8 feet to obtain a total wind load of 320 pounds on the stud. One-half of the total load is transmitted to each end of the stud--160 pounds at each stud-to-plate connecti

The acceptable level of joint deformation was set at 0.005 inch for end-naile joints and 0.010 inch for toe-nailed joints on the basis of results of a test by Walker (in press). Walker's test showed that after deformation of COM-PLY studs exceeded 0.005 inch in end-nailed joints and 0.010 inch in toe-nailed joints, the joints were no longer elastic. Allowing larger joint deformations results in permanent set in the joints.

PERFORMANCE STANDARDS FOR COM-PLY STUDS

GENERAL

When a sample of COM-PLY studs meets the performance standards presented he then studs manufactured to essentially the same specification are acceptable for use in one- and two-story multi-family dwellings. Such studs will be acceptable to any building code agency that has adopted these performance standards as a method of code approval. The sample tested must be randomly selected from COM-P studs representative of those proposed for commercial use.

The initial sample submitted to a testing laboratory must contain 40 specimens: 10 for each of the four tests (structural strength and stiffness, durability, dimensional stability, and strength of nailed joints). If this sample meets all the performance levels required, then the design is considered acceptable. If the results of any test are slightly below the level required, then 10 additional specimens may be tested and the results averaged with those of the previous test. Such averaging may raise the test results to an acceptable level. There is seldom any advantage to testing more than 30 studs for a given property.

Evaluating the performance of COM-PLY studs with these standards requires that a numerically expressed value or standard level for acceptance be established for each property tested. A laboratory test for each property is then performed, and the numerical test value is adjusted to account for variation in the population of studs as well as the factors of safety, duration of load, and load sharing. This adjusted value is then compared with the standard level for that property and the studs are accepted only if the adjusted value equals or exceeds the standard level.

When possible, the manufacturer should provide the testing laboratory with the following information on the COM-PLY studs submitted:

- -Thickness of veneers
- -Species or combinations of species used for veneer
- -Quality of veneer
- -Type and spread rate of laminating adhesive
- -Geometry of wood particles in the particleboard
- -Percentage and type of particleboard binder
- -Percentage and type of particleboard wax
- -Internal bond of particleboard
- -Density of particleboard
- -Thickness swelling of particleboard
- -Linear expansion of particleboard
- -Modulus of elasticity of particleboard
- -Modulus of rupture of particleboard
- -Trademark identifying specifications to which COM-PLY studs were made

Properties of the particleboard core such as internal bond, density, thickness swelling, linear expansion, MOE and MOR should be determined by the standard methods set forth in ASTM D 1037-72a (ASTM 1975a).

All specimens must be tested at a moisture content of 10 ± 2 percent. This moisture content can be attained by conditioning studs to constant weight under controlled temperature and relative humidity: for example, 80° ± 6° F (27° ± 3° C) and a relative humidity of 65 ± 1 percent, or an equivalent combination.

After completing the tests, the laboratory should report the following information to the manufacturer:

- -Number of specimens tested in each evaluation
- -Test values for individual specimens
- -Average test values

-Standard deviation of test values

-Computation of adjusted values for the population of studs

-Explanatory notes on any unusual modes of failures

STRUCTURAL STRENGTH AND STIFFNESS

Standard Level

The standard level for strength requires that a COM-PLY stud simultaneously withstand a transverse bending load equivalent to 40 pounds per linear foot and an axial compressive end load of 1,190 pounds applied concentrically. The transverse bending load acts in the plane of the 3-1/2-inch dimension of the stud. The standard level for stiffness requires that a COM-PLY stud not deflect more than 0.412 inch under two concentrated loads of 112.5 pounds at the quarter points of the span.

Laboratory Test

The bending load can be applied with a universal testing machine, hydraulic cylinders, or any equivalent device. Because most laboratories use the universal testing machine, the loading method most appropriate for that device will be described here. With this method, two concentrated bending loads are applied to the specimen (fig. 4). For a given loading, this method will induce the same maximum bending moment in the specimen as a uniformly distributed bending load. However the maximum bending moment is continuous between the concentrated loads, whereas it occurs only at mid-span with uniformly distributed loads. With either loading method, the load per linear foot is computed by dividing the total downward load by 7.5 feet (the test span).

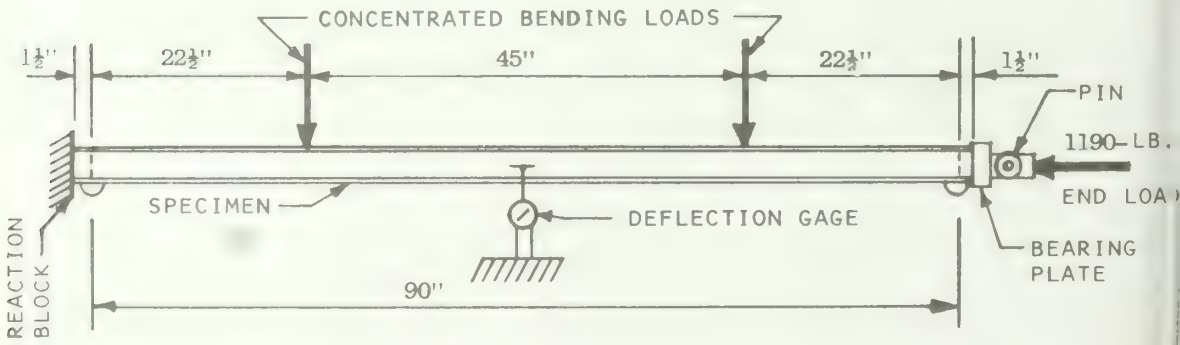

Figure 4.--Loading method for bending test.

The COM-PLY specimen rests on two steel roller supports 90 inches apart. The area supporting the stud must be sufficient to prevent bearing failure during the test. The specimen must also be laterally supported to prevent sideways buckling, but the supports must not resist the downward bending load.

The axial compressive end load is applied to the specimen with a hydraulic cylinder through a pinned bearing plate. This axial load is resisted at the opposite end of the specimen by a fixed reaction block that bears fully on the end cross-section of the specimen. The bending and axial loading machine or load measuring apparatus must comply with the requirements prescribed in ASTM

Methods E-4, Standard Methods of Verification of Testing Machines (ASTM 1975e). The gage pressure of hydraulic cylinders applying axial compression must be calibrated against the force exerted on the hydraulic cylinder by a universal testing machine.

The two concentrated loads are applied to the specimen at quarter points through blocks which bear across the entire width of the specimen; the bearing length must not be less than 1-1/4 inches. These loads are applied through a system of pins, rollers, and knife-edge bearing points to assure uniform distribution and to prevent introducing secondary stresses in the specimen as it deflects under test loading (fig. 5).

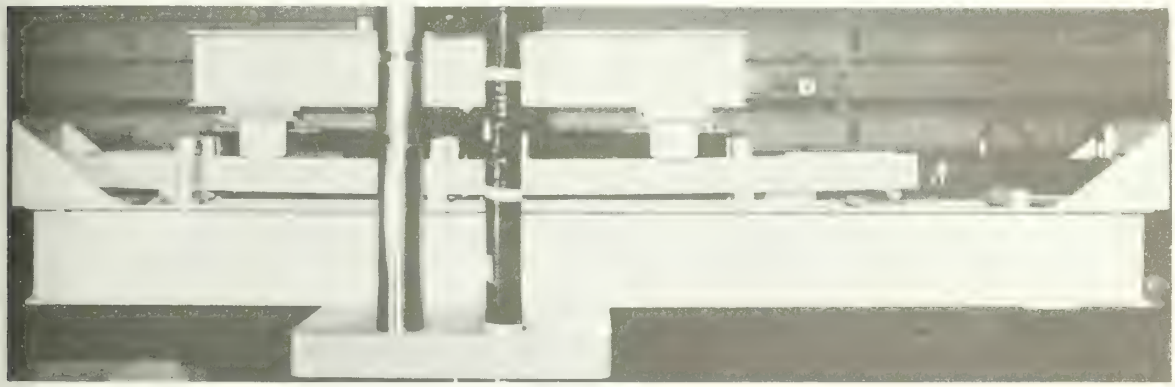

Figure 5.--COM-PLY stud under combined loading in a universal testing machine.

The mid-span deflection of the test specimen during loading is measured with a dial gage that reads to the nearest 0.001 inch. The gage is mounted on a frame or yoke supported on pins through the specimen at the neutral axis and directly over the roller supports (fig. 6). This arrangement prevents the deflection readings from being affected by any settling of the supports.

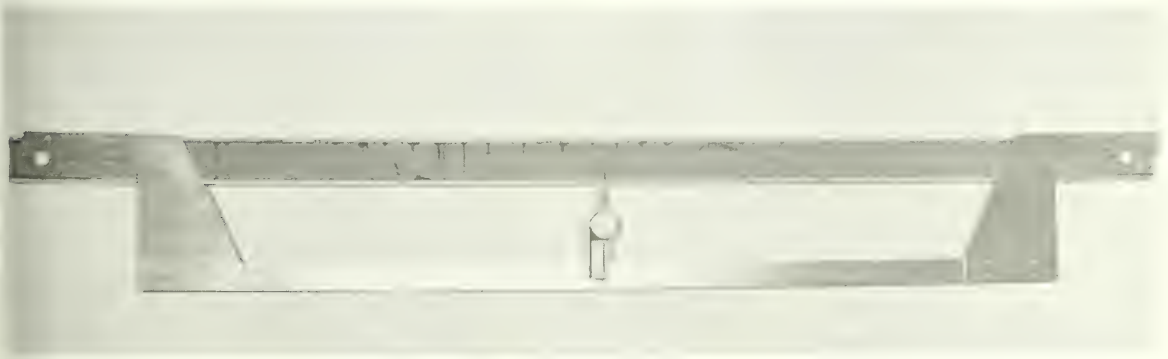

Figure 6.--Dial gage mounted on a frame with supports at ends of the specimen.

Place the specimen on the two roller supports. Then place the frame with mounted gage on the support pins at the ends of the specimen. Next, apply the 1,190-pound axial compressive load to the end of the specimen. Record the initial

gage reading with the axial load applied but with no bending load other than the specimen's own weight. Apply a continuously increasing bending load to the specimen at a constant rate (pounds per minute) or head speed (inches per minute) until ultimate load is reached and the specimen fails. Ultimate load is reached when deformation occurs at an increasing rate per unit of time with no increase in load or when the test specimen has collapsed. Select a rate of load or head speed that will result in failure in not less than 6 nor more than 20 minutes. For specimens of average strength and stiffness, a rate of load of 80 pounds per minute or head speed of 0.2 inch per minute would be typical. Figure 7 shows a typical tension failure in the veneers of a COM-PLY stud.

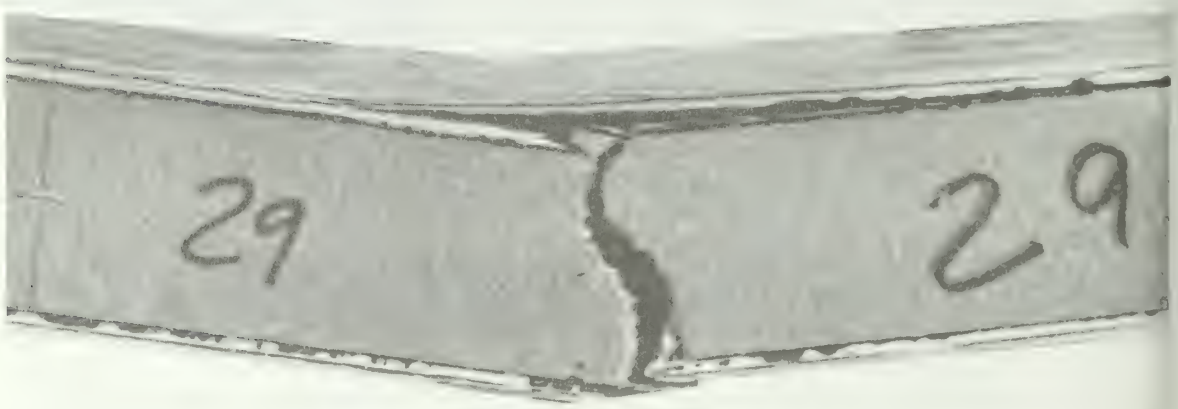

Figure 7.--Typical tension failure in the veneers of a COM-PLY stud.

During loading to failure, read the gage and record deflection at sufficiently close intervals to plot a load-deformation curve. Load intervals of 80 to 100 pounds are typical. Also record the deflection occurring when the total bending load reaches 225 pounds. If necessary, this deflection can be determined by interpolating between the readings for loading points immediately below and above 225 pounds.

In the test report, record the ultimate load and the mode and location of failure for each specimen, as well as the average deflection of the specimens under a 225-pound bending load. The test report should also include a complete description of the test specimens, their moisture content, the testing apparatus, and the method of loading.

Determining Acceptability

The values for strength and stiffness of the test studs must be adjusted to determine the actual load such studs can be expected to carry safely. These adjusted values must then be compared with the performance standard. For strength the adjusted value is computed by the following formula:

$$W = \left[\bar{w} - \frac{t_{0.05} S}{\sqrt{N}} - t_{0.05} S \right] \frac{F_r}{F_s F_t}$$

where:

W = adjusted value for load in pounds per linear foot of stud

$\bar{w}$ = average ultimate test load in pounds per linear foot of stud

$t_{0.05}$ = statistical t at 0.05 confidence level for N - 1 degrees of freedom

S = standard deviation of ultimate test loads in pounds per linear foot of stud

N = number of test specimens

F_r = allowable increase for load sharing among adjacent wall studs in typical wall framing; use 1.15

F_s = safety factor; use 1.5

F_t = adjustment for the ratio of the duration of the test load to the duration of the service load. In this case, the service load is assumed to be the wind load, and the factor for the duration of this load is 1.33. If the test load is applied over an average period of 15 minutes, the factor for the duration of this load is 1.57. In this example, the test load is applied faster than the service load, so the adjustment factor is 1.57/1.33 or 1.18 (Hunt and others 1973; ASTM 1975b).

The strength of the stud design is acceptable if the value for W is 40 or greater.

For stiffness, the adjusted value is computed by the following formula:

$$D = \bar{d} + \frac{t_{0.05} S}{\sqrt{N}}$$

where:

D = adjusted value for midspan deflection in inches

$\bar{d}$ = the average midspan deflection of N test studs when two 112.5-pound test loads are applied

$t_{0.05}$ = statistical t at 0.05 confidence level for N - 1 degrees of freedom

S = standard deviation of midspan deflections under two 112.5-pound test loads

N = number of specimens

The stiffness of the stud design is acceptable if the value for D is 0.412 inch or less.

DURABILITY

Standard Level

The standard level for durability requires that, after cyclic exposure to heat and moisture, a COM-PLY stud must have an adjusted value for strength not less than 50 percent of and an adjusted value for deflection not more than 100 percent greater than the corresponding values for unexposed studs.

Laboratory Test

The specimens are subjected to six cycles of accelerated aging, each cycle consisting of five exposures at varying temperatures and moisture contents. The five exposures that make up one accelerated aging cycle are as follows:

(1) Immerse all specimens for 1 hour in a tank filled with tap water maintained at 120° ± 3° F (49° ± 2° C). The immersion tank (fig. 8) should be essentially free from corrosion. Separate the specimens so that all surfaces are in contact with the water.

Figure 8.--Tank used at the Forestry Sciences Laboratory for water soaking and steaming specimens.

(2) Place the specimens in a closed vessel and spray them for 3 hours with steam at atmospheric pressure. Maintain the temperature inside the vessel at 200° ± 5° F (93° ± 3° C).

(3) Place the specimens in a dry kiln or drying oven and circulate air around the specimens at the rate of 100 to 300 feet per minute for 3 hours (fig. 9). The circulated air must be heated to 210° ± 3° F (99° ± 2° C) with a relative humidity of 40 ± 5 percent. Space the specimens at least 3/4 inch apa so that all surfaces are exposed.

(4) Repeat exposure 2.

(5) Repeat exposure 3, but maintain it for 18 instead of 3 hours.

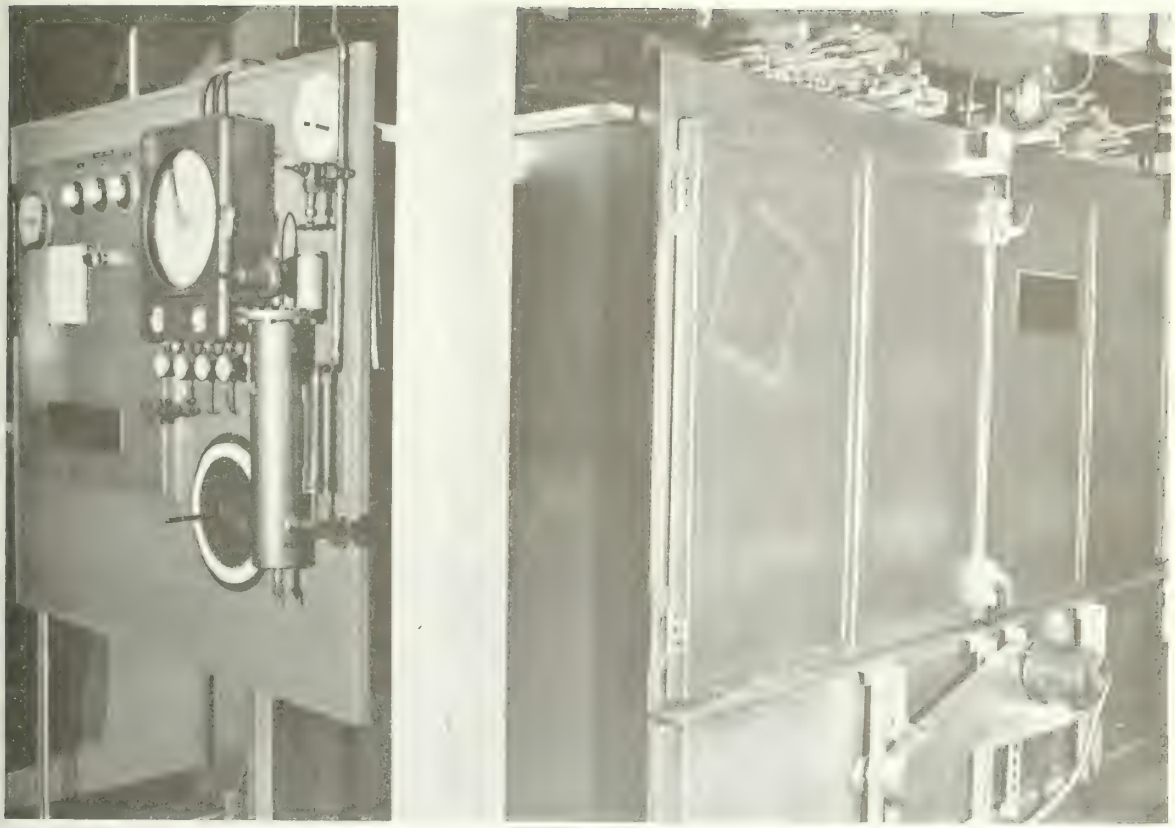

Figure 9.--Dry kiln used at the Forestry Sciences Laboratory for drying specimens.

Inspect the specimens after each cycle of five exposures for any visible sign of delamination or other disintegration and describe such signs in the test report.

After completing six cycles of accelerated aging, bring the specimens to a moisture content of 10 $\pm$ 2 percent by conditioning them to constant weight under controlled temperature and relative humidity. Then test all specimens for structural strength and stiffness. The rates of load or head speed during loading may have to be decreased so that ultimate loads occur in not less than 6 nor more than 20 minutes.

Determining Acceptability

The test values for strength and stiffness must be adjusted by the same formulas used in the previous test. The durability of COM-PLY studs is acceptable if the exposed specimens have an adjusted value for strength not less than 50 percent of and an adjusted value for deflection not more than 100 percent greater than the corresponding values for unexposed studs.

DIMENSIONAL STABILITY

Standard Level

The standard levels for dimensional stability require that, after water soaking, average dimensional increases of all COM-PLY specimens not exceed 8.0 percent for width and thickness and 0.1 percent for length and that the average warpage not exceed 0.75 inch for bow, 0.375 inch for twist, and 0.25 inch for crook.

Laboratory Test

Bring the specimens to a moisture content of 10 ± 2 percent by conditioning them to constant weight under controlled temperature and relative humidity. Then, at quarter and mid-points along the length of each specimen, measure its width and thickness at the center of each face to the nearest 0.001 inch. Mark the points of measurement on the specimens. Then place each stud in a metal frame so that one end rests against a fixed stop and the other end rests against the stem of a dial gage incremented to 0.001 inch (fig. 10). A calibration rod measured to the nearest 0.1 inch may be used to determine the distance between the fixed stop and the gage stem when the dial points to zero. Record the length of each specimen for later comparison after water soaking. Finally, measure the amount of warpage in all specimens according to the methods found in lumber grading rules.

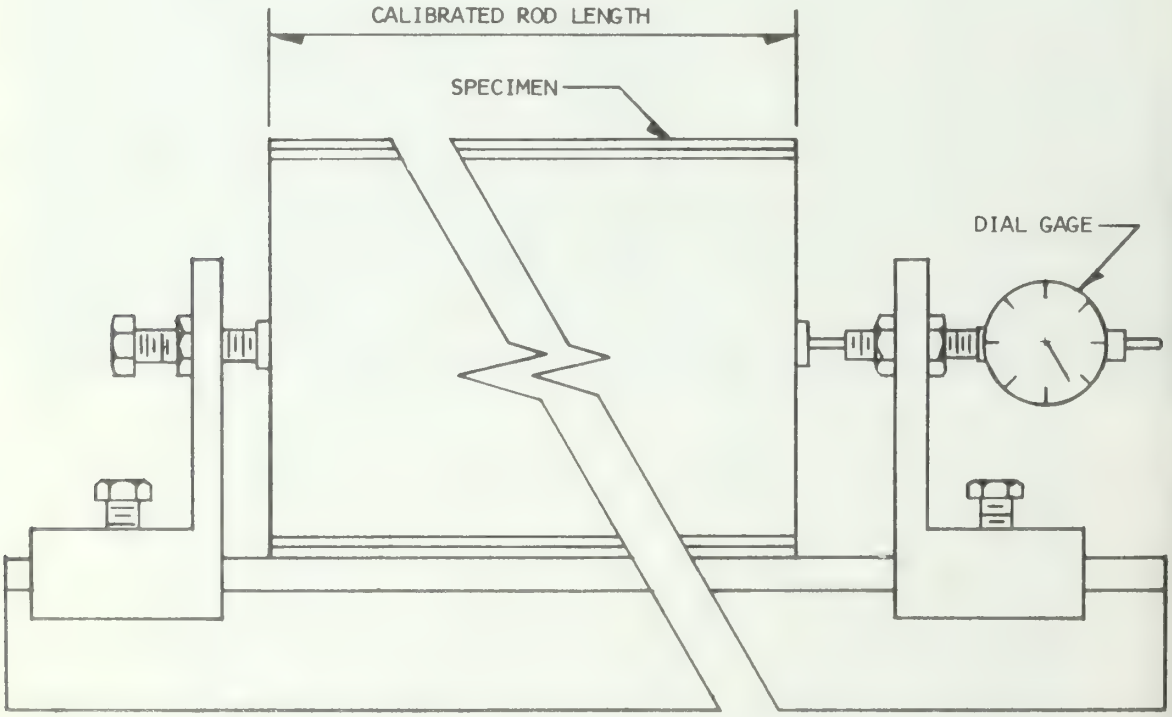

Figure 10.--Apparatus for measuring length of studs before and after water soaking.

After all specimens have been measured, immerse them in water at 68° ± 6° F (20° ± 3° C) for 24 hours. Separate the specimens with spacer blocks so that all surfaces are in contact with the water. After the soaking, remeasure all specimens at the same locations to obtain relative increases in width, thickness, and length. Then measure the amount of warpage in each.

Determining Acceptability

Compute the average percentage of increase in width, thickness, and length for the test specimens after water soaking, as well as the average warpage in bow, twist, and crook. Compare these averages with the standard level to determine whether dimensional stability of the studs is acceptable.

STRENGTH OF NAILED JOINTS

Standard Level

The standard level for lateral load strength of end-nailed and toe-nailed joints between the end of the stud and the wall plate is 150 pounds. The standard level for lateral deformation of end-nailed joints of this type is 0.005 inch and that for toe-nailed joints of this type is 0.010 inch.

Laboratory Test

The laboratory test requires that specimens of end- and toe-nailed joints between a COM-PLY stud and a wall plate be fabricated (figs. 11 and 12). For the plates in each specimen, use 12-inch-long solid pieces of sawn 2 x 4 studs of medium-to-low density, such as spruce. For the COM-PLY portions, cut two 16-inch-long sections from each of the 10 studs submitted for this test. Use one section from each stud in an end nailed specimen and the other in a toe-nailed specimen.

Figure 11.--Test specimen of end-nailed joint.

For the end-nailed specimens, drive two 16d box nails between 3/4 and 1 inch from the edge of the plate. For the toe-nailed specimens, drive two 8d common nails on each side of the stud about 7/8 inch from its end. The angle between these nails and the stud must not exceed 45 degrees. Drive the toe nails between 3/4 and 1 inch from the edge of the stud, and stagger them slightly in relation to the toe nails on the opposite face.

Figure 12.--Test specimen of toe-nailed joint.

For test loading, place the specimen on the roller and fixed supports on the bed of a universal testing machine (fig. 13). Clamp or bolt the plate to a rigid frame or angle to prevent rotation during test loading. Mount a dial gage incremented to 0.001 inch on a bracket screwed to the plate so that the stem of the

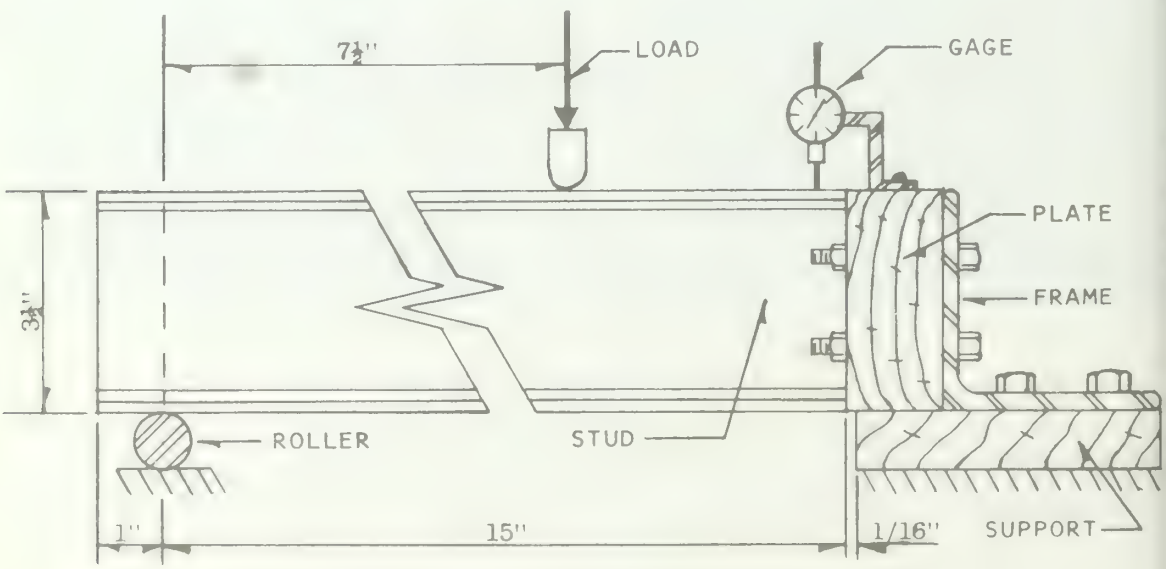

Figure 13.--Loading method for testing specimens of nailed joints.

gage rests on the stud. This arrangement will permit reading deformation between the stud and the plate during test loading. Record the reading with no load applied to the specimen. Load must be applied to the specimen through a bearing block essentially like the bearing block described in paragraph 47 of ASTM D 143 (ASTM 1975d). Apply load uniformly and continuously to the specimen at a rate of 100 pounds per minute or a head speed of 0.010 inch per minute until ultimate load occurs. Record ultimate loads for all specimens.

During loading to failure, read the gage and record the joint deformation at load increments of 100 pounds. Also record the joint deformation at 320 pounds of test load (160 pounds of joint load).

Make separate determinations for toe-nailed and end-nailed specimens. For each group, determine the average deformation at 320 pounds of load and the average ultimate load. In the test report, describe all specimen failures such as rupture or nails bent and withdrawn.

Determining Acceptability

The values for lateral load and deformation of the end-nailed and toe-nailed specimens must be adjusted to determine the actual load such joints can be expected to carry safely. These adjusted values must then be compared with the performance standard. For each group of specimens, the adjusted value for load is computed by the following formula:

$$P = \left[\bar{p} - \frac{t_{0.05} S}{\sqrt{N}} - t_{0.05} S \right] \frac{1}{F_s F_t}$$

where:

P = adjusted value for load in pounds per joint

$\bar{p}$ = one-half of the average ultimate test load in pounds

$t_{0.05}$ = statistical t at 0.05 confidence level for N - 1 degrees of freedom

S = standard deviation of ultimate joint loads (one-half of ultimate test load) in pounds

N = number of test specimens

F_s = factor of safety, use 1.5

F_t = adjustment for the ratio of the duration of the test load to the duration of the service load. In this case, the service load is assumed to be the wind load, and the factor for the duration of this load is 1.33. If the test load is applied over an average period of 15 minutes, the factor for the duration of this load is 1.57. In this example, the test load is applied faster than the service load; therefore, the adjustment factor is 1.57/1.33 or 1.18 (Hunt and others 1973; ASTM 1975b).

The lateral load capacity of joints made with the test studs is acceptable if the value of P is 160 or greater for both end-nailed and toe-nailed joints.

For each group of specimens, the adjusted value for joint deformation is computed by the following formula:

where:

D = adjusted value for joint deformation of stud relative to plate, in inches

$\bar{d}$ = the average joint deformation on N test joints when a 160-pound load (320-pound test load) is applied to the joint

$t_{0.05}$ = statistical t at 0.05 confidence level for N - 1 degrees of freedom

S = standard deviation of joint deformations under a 160-pound joint load (320-pound test load)

N = number of specimens

The lateral load deformation of joints made with the test studs is acceptable if the value of D is less than 0.005 inch for end-nailed joints and 0.010 inch for toe-nailed joints.

DISCUSSION

As part of the research to develop COM-PLY studs, approximately 3,200 of the new studs were fabricated with production line equipment. Performance tests made according to these standards on a randomly selected sample indicated that the studs were acceptable for home building. Approximately 1,500 of the COM-PLY studs were installed in four demonstration houses at various locations in the United States. At the building sites, these studs were stored under conditions varying from freezing temperatures with snow to warm temperatures with rain. Thus far, performance of the studs in the houses has been excellent, indicating that the standards developed are adequate.

These standards should prove useful to potential manufacturers of COM-PLY studs. After selecting the thickness and number of veneers, species of wood, laminating adhesive, and particleboard resin binder that appear economically feasible to use, the manufacturer can determine from these standards whether the proposed design is acceptable for house construction.

Although these standards were developed for COM-PLY studs in wall framing, they could also be used to evaluate the performance of other studs made from wood composites. For example, with these standards, studs made entirely of particleboard, wood veneer laminates, or hardboard could be evaluated for acceptability in home building.

RECOMMENDATIONS

Further research on evaluating the durability of COM-PLY studs is needed so that a laboratory test well correlated with outdoor weathering can be developed. Research is also needed on how the various characteristics of particleboard affect the strength of nailed joints. The lower limits of particleboard density and internal bond that will provide satisfactory joints are not well defined, nor has the effect of particle geometry on joint strength been fully investigated.

We recommend that the demonstration houses be inspected every five years to see if actual performance of COM-PLY studs reveals the need for changes in these standards.

LITERATURE CITED

American Society for Testing and Materials
1975a. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. D 1037-72a. ASTM Stand., Part 22, p. 275-316.

American Society for Testing and Materials
1975b. Standard methods for establishing clear wood strength values. D 2555-73. ASTM Stand., Part 22, p. 715-736.

American Society for Testing and Materials
1975c. Standard methods of testing metal fasteners in wood. D 1761-74. ASTM Stand., Part 22, p. 522-537.

American Society for Testing and Materials
1975d. Standard methods of testing small clear specimens of timber. D 143-52. ASTM Stand., Part 22, p. 34-91.

American Society for Testing and Materials
1975e. Standard methods of verification of testing machines. E 4-72. ASTM Stand., Part 10, p. 75-80.

Dixon, Wilfrid J., and Frank J. Massey, Jr.
1969. Introduction to statistical analysis. 3d ed. 638 p. McGraw-Hill, New York.

Duff, John E.
1972. Vapor barrier decreases moisture conditions in wood walls exposed to air conditioning and heating. U.S. Dep. Agric., For. Serv., Res. Pap. SE-98, 8 p. U.S. Dep. Agric., For. Serv., Southeast. For. Exp. Stn., Asheville, N.C.

Duff, John E.
In press. Dimensional stability and durability of composite studs. U.S. Dep. Agric., For. Serv., Res. Pap. SE- . U.S. Dep. Agric., For. Serv., Southeast. For. Exp. Stn., Asheville, N.C.

Hann, R. A., J. M. Black, and R. F. Blomquist
1962. How durable is particleboard? For. Prod. J. 12:577-584.

Heebink, B. G., and F. V. Hefty
1969. Treatments to reduce thickness swelling of phenolic-bonded particleboard. For. Prod. J. 19:17-26.

Hunt, M. O., D. A. Fergus, and S. K. Suddarth
1973. Improved graphic presentation of duration of load effect for wood. Purdue Univ., Spec. Publ. F-65, 7 p.

Kuenzi, E. W.
1955. Theoretical design of a nailed or bolted joint under lateral load. U.S. Dep. Agric., For. Serv., For. Prod. Lab. Rep. D1951, 24 p. U.S. Dep. Agric., For. Serv., For. Prod. Lab., Madison, Wis.

National Forest Products Association
1973. National design specification for stress-grade lumber and its fastenings. Natl. For. Prod. Assoc., Washington, D.C., 50 p.

Scholten, John A., and E. G. Molander
1950. Strength of nailed joints in frame walls. J. Am. Soc. Agric. Eng. 31:551-555.

Walker, Roy M.
In press. Structural performance of nailed joints with COM-PLY studs. U.S. Dep. Agric., For. Serv., Res. Pap. SE- . U.S. Dep. Agric., For. Serv., Southeast. For. Exp. Stn., Asheville, N.C.

Whittemore, Herbert L., John B. Cotter, Ambrose H. Stang, and Vincent B. Phelan
1948. Strength of houses: application of engineering principles to structural design. U.S. Dep. Commer. Rep. BMS 109, 132 p.

Wilkinson, Thomas Lee
1972. Analysis of nailed joints with dissimilar members. J. Struct. Div., Proc. Am. Soc. Civil Eng. 98(ST9):2005-2013.

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Environmental Change After Site Preparation and Slash Pine Planting on a Flatwoods Site

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Abstract.--On a flatwoods site in north Florida, disking or disking + bedding greatly reduced the frequency, density, and dry weight of most shrubs and changed the predominant vegetation from Serenoa repens, Ilex glabra, and Sporobolus curtissii to Panicum spp. and Xyris spp. Bedding produced the most adverse temperature, moisture, insolation, and wind effects. Early slash pine survival was significantly improved by mechanical site preparation, and superior trees grew significantly faster than commercial stock. By age 4, trees growing on beds averaged only 0.3 m taller than trees growing without the benefit of site preparation.

Keywords: Site treatment, Pinus elliottii Engelm., vegetation change, soil properties.

There is an increasing trend toward complete, mechanical destruction of coastal plain vegetation to provide clear, tilled sites for planting southern pine seedlings. Mechanical site preparation usually includes ditching, chopping, disking, bedding, or a combination of two or more treatments (Worst 1964; McMinn 1969; Schultz 1973). This concentrated tillage immediately alters basic soil, moisture, and floral patterns and is expected to enhance tree growth (Haines and Pritchett 1965; Langdon 1962; Lewis 1970). The tree growth advantage of intensive site preparation, such as disking or disking and bedding, over no preparation or burning only is uncertain and on some sites may not pay for treatment costs. Of greater concern, however, is the possibility that intensive culture irreversibly alters flatwoods ecosystems and destroys some species of vegetation.

In the present study, I monitored changes in soil, moisture, vegetation, and microclimate associated with varying intensities of site preparation followed by planting slash pine (Pinus elliottii Engelm.) on an Atlantic Coastal Plain flatwoods site.

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METHODS

The study area is a typical flatwoods site in Baker County, Florida. The soil is an imperfectly drained Leon fine sand (Aeric Haplaquod) which has a spodic horizon ranging from a stain layer to areas of hard concretions at depths of 30 to 45 cm below the soil surface. Only a small portion of this spodic horizon appears hard enough to severely restrict root growth.

The area was cleared of a sparse stand of 60-year-old longleaf pine (fig. 1) in 1968 and left untouched until the spring of 1970. The predominant shrubs included saw-palmetto (Serenoa repens (Bartr.) Small) and gallberry (Ilex glabra (L.) Grey) while the most common herbaceous cover consisted of Curtiss dropseed (Sporobolus curtissii (Vasey) Small) and Beardgrass (Andropogon spp.).

Figure 1.--Study area prior to clearcutting and site treatment. Saw-palmetto appears to be dominant even though it covers only 25 percent of the area.

EXPERIMENTAL TREATMENTS

Sites were prepared in four ways: no treatment (control); burn only (burn); burn and double disk (disk); burn, and double disk and bed (bed). Two types of slash pine seedlings (genetically superior for juvenile growth rate and unimproved commercial stock) were planted after each of the four preparation treatments. In all, 24 treatment plots (each 30.5 X 21.3 m) were established in a randomized block experimental design consisting of three replications, four site treatments, and two types of planting stock.

Plots were site prepared in the spring of 1970. Prescribed backfires consumed most of the vegetation, leaving only the woody stems of shrubs standing. A heavy-duty offset harrow was used to disk the soil. A bedding harrow and water-filled rolling hourglass packer pulled the disked soil into long, parallel mounds 15 cm above the normal groundline and 3 meters apart.

The superior slash pine (10 families) and commercial stock were grown in a commercial nursery and outplanted as 1-0 bare-rooted seedlings during a 4-day period in February 1971. Tree spacing was 3 m x 2.2 m. Between plots 13-m isolation strips were planted with the same stock as in the commercial seedling plots. Tree heights were measured after planting and at the end of each of the first four growing seasons. Insect and animal damage was recorded after each of the first three growing seasons.

Average climatic, soil, and vegetation conditions prior to treatment (1970) and 2 to 4 years after treatment were compared by graphic and variance analyses. Statistical significance in this paper will be at the 0.05-level of probability unless otherwise noted.

FLORAL MEASUREMENTS

Two permanent 30.5-m line transects were randomly located in each of the 24 plots. Each transect was divided into 15-cm segments. Occurrence in segments was recorded for species or species groups. These frequency counts were made in March 1970 (prior to site preparation), and again in May 1972--approximately 2 years after site preparation. Four 30 X 120 cm rectangular quadrats were randomly located near one line transect in each plot. All vegetation in each of these quadrats was destructively sampled in March 1970, separated by species group, ovendried at 105° C, and weighed to estimate the amount of secondary vegetation on the area following cutting of the overstory pine but prior to any cultural treatment. In July 1972, four additional quadrats were destructively sampled to estimate the effect of site preparation on species composition and to determine the dry weight of understory vegetation 2 years after treatment.

MICROCLIMATIC MEASUREMENTS

Microenvironmental instruments were installed on the study area in the spring of 1970 and operated until October 1973. A recording rain gauge was located 1.3 m above ground level on the south edge of the study, and a pyrheliograph was positioned 1 m above ground in the center of the study. Totalizing 3-cup anemometers positioned at 0.5 m or 1.5 m above the soil surface[2] monitored wind movement in the control, disked, and bedded plots as well as under a stand of mature longleaf located to one side of the study. Hygrothermographs and soil thermographs continuously monitored temperatures at 44 cm above ground as well as 2.5 and 23 cm below ground in the control, disked, and bedded plots, and in the longleaf stand. Maximum-minimum thermometers placed 23 cm above ground in all treatments were read five times each week.

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[2] Anemometer on the bedded plot was placed on the top of a bed, thus extending it 15 cm higher than for other treatments.

Coleman[3] soil moisture cells were positioned at 2.5, 7.5, and 23 cm below ground in one plot of each treatment and were read two to four times each week. Two water wells were located in each of the four treatments; water table levels were monitored weekly.

EDAPHIC MEASUREMENTS

Soil samples at 0 to 15 and 15 to 30 cm depths were taken prior to and $2\frac{1}{2}$ years after site preparation to determine pre- and post-treatment chemical and physical properties. Twenty random cores were taken on each plot with a soil sampling tube, composited, air dried, sifted through a 20-mesh sieve, thoroughly mixed, and subsampled for analysis. Post-treatment sampling on bedded plots included separate samples for three microsites: top of beds, furrows alongside of beds, and disked area between beds. The pH was determined from a 1:1.5 soil-water slurry. Organic-matter (OM) content was obtained by dry-ashing duplicate 20 g samples at 700° C for 1 hour. The loss in weight on ignition was computed as a percent of ovendry sample weight. Total nitrogen (N) was determined by Kjeldahl analysis of-20 g samples. Potassium (K), calcium (Ca), Magnesium (Mg), and sodium (Na) were extracted with neutral N ammonium acetate and were analyzed by atomic absorption. Available phosphorus (P) was determined by the Bray No. 2 extraction procedure (Bray and Kurtz 1945).

Soil texture was determined by the Bouyoucos hydrometer method (Day 1956). Bulk density, specific gravity, and percent pore space were determined in undisturbed soil cores.

RESULTS

SOIL MEASUREMENTS

There was little variation in soil texture among the plots. The surface 30 cm was composed of 96 percent sand, 3 percent silt, and 1 percent clay. The total extractable metallic cations averaged 1.8 meq/100 g at 0-15 cm and 2.0 meq/100 g at 15-30 cm. Although these figures are low, they are consistent with the normally low cation exchange capacity in this soil type (Humphreys and Pritchett 1971; Schultz and Wilhite 1974).

Before treatment bulk density was 1.15 g/cm^3, specific gravity was 2.0 g/cm^3 and pore space averaged 43 percent. Two and one-half years after disking and bedding these figures were not significantly different than before treatment, indicating that disked and bedded areas had returned to normal in these important physical properties.

Site preparation significantly altered the 1972 levels of K, Ca, and Mg because the nutrient-rich surface soil was removed from furrows and deposited on top of the beds. Compared to no treatment, bedding significantly increased K in the surface 15 cm by 3.7 p/m. Burn-only plots had significantly less K and Ca in the surface 15 cm than beds did.

[3] Mention of commercial products does not imply endorsement by USDA to the exclusion of other products which may be suitable.

Significant treatment x year interactions for OM, K, Ca, and Mg indicate that time did not have the same effect on all treatments. Individual analyses established that bedding was the treatment which had the greatest overall effect on these elements. Disking reduced OM in the surface 15 cm from 2.9 percent prior to treatment to 2.4 percent $2\frac{1}{2}$ years after treatment (table 1). In contrast, OM on the control and the beds on bedded plots increased from 2.2 and 2.8 percent prior to treatment to 2.5 and 2.9 percent after treatment. Furrowed areas of bedded plots had 1.3 percent less OM after treatment than prior to treatment. Nitrogen levels showed the same trend but changes were not statistically significant. The increased OM in control plots can be attributed to the decomposition and incorporation of logging slash. Much slash was consumed when the other plots were burned.

Table 1.--Soil reaction and fertility before and 2 years after site preparation

Treatment	pH	OM	N	P	K	Ca	Mg	Na
	Units	Percent			Parts per million			
0-15 CM PRIOR TO SITE PREPARATION (1970)								
No treatment	4.4	2.2	358	3.3	10.3	43.7	19.0	6.3
Burn	4.3	3.1	503	3.1	12.0	43.0	22.0	9.0
Burn+disk	4.2	2.9	467	2.9	15.0	56.7	26.0	16.3
Burn+disk+bed	4.1	2.8	467	2.9	14.3	58.3	25.0	10.0
15-30 CM PRIOR TO SITE PREPARATION (1970)								
No treatment	4.9	1.3	228	7.0	5.7	14.7	6.3	6.3
Burn	4.9	1.3	223	4.8	3.0	8.0	4.0	3.0
Burn+disk	4.6	1.2	212	3.2	5.3	19.0	8.3	6.7
Burn+disk+bed	4.5	1.0	172	2.2	4.3	20.3	8.3	6.7
LSD (0.05)[1]	.3	.8	135	6.2	3.8	34.8	11.7	14.4
0-15 CM 2 YEARS AFTER SITE PREPARATION (1972)								
No treatment	4.2	2.5	405	2.3	12.0	48.7	19.3	6.3
Burn	4.4	2.7	438	4.6	11.7	34.7	22.0	7.7
Burn+disk	4.3	2.4	397	2.6	13.7	63.3	29.3	9.0
Burn+disk+bed	4.2	2.9	487	2.8	15.7	76.3	29.3	5.7
Flat	4.3	2.5	418	3.6	14.0	69.3	26.7	8.3
Furrow	4.6	1.5	253	2.7	10.3	44.3	16.7	5.7
15-30 CM 2 YEARS AFTER SITE PREPARATION (1972)								
No treatment	4.8	1.4	263	6.5	4.3	14.3	6.0	4.7
Burn	4.9	1.4	242	2.1	5.7	13.3	6.7	5.7
Burn+disk	4.9	1.3	227	6.5	5.3	19.0	9.3	5.7
Burn+disk+bed	4.5	1.7	290	4.5	8.3	46.3	20.3	6.3
Flat	4.9	.9	193	2.3	4.3	24.0	10.0	4.3
Furrow	4.9	1.6	273	12.7	4.7	15.3	8.3	6.0
LSD (0.05)[1]	.4	.8	206	5.8	3.3	37.0	10.9	2.9

[1] Tests compare all microsites within each sampling period

Except for Na and P, there was less of each element at 15 to 30 cm than at 0 to 15 cm. The construction of shallow furrows on each side of the beds removed most of the surface 15 cm of soil. Consequently, pH and nutrient levels in the surface 15 cm of furrows were much the same as those occurring at 15 to 30 cm depth in other treatments.

SECONDARY VEGETATION

Before treatment, plots had similar dry weights or frequencies of species groups, except for saw-palmetto which had an extremely high dry weight on burn-only plots (tables 2 and 3). The mean dry weight of all vegetation was 780 g/m^2 with 95 percent confidence limits of ± 15 percent. The weight of herbaceous vegetation exceeded that of shrubs by 17 percent.

Table 2.--Dry weight of understory vegetation before and 2 years after site preparation

Plant	No treatment (control)		Burn only (burn)		Burn+disk (disk)		Burn+disk+bed (bed)		Significance[3]		
	1970	1972	1970	1972	1970	1972	1970	1972	Treatment (1972)	Year	Treatment x year
	Dry weight (g/m^2)										
Grasses											
Andropogon spp.	83.2	21.0	32.4	33.3	74.4	44.9	250.5	72.5			
Aristida spiciformis	(1)	0.9	(1)	8.1	(1)	18.0	(1)	20.7			
Aristida stricta	10.4	9.7	57.0	41.9	29.5	0.5	15.1	5.1			
Panicum spp.	7.9	1.2	11.5	9.5	14.8	153.2	19.3	192.6	**	**	**
Paspalum spp.	(2)	.0	(2)	0.5	(2)	.6	(2)	1.5			
Sporobolus curtissii	242.8	154.8	244.8	212.2	268.8	35.6	195.9	4.8	*		
Other grasses	.4	3.5	3.4	11.4	1.9	20.6	6.4	4.0	*		
Sedges	.6	.6	0.3	1.3	1.4	1.5	.0	2.0		*	
Rushes	.0	.8	.0	3.1	.0	9.0	.0	11.7			
Mosses	11.4	3.3	11.2	2.4	7.6	2.7	10.8	.3			
Forbs											
Compositae	3.6	2.8	2.7	8.0	24.8	9.9	27.3	5.5			
Leguminosae	.0	.2	.0	.4	.0	.1	.0	.1			
Xyris spp.	1.4	.1	.6	.2	.9	11.0	2.9	10.2			*
Other forbs	.3	.1	3.8	6.5	1.5	5.1	1.3	6.5		**	
Total Herbs	361.1	199.0	367.7	338.8	425.6	312.7	529.5	337.5			
Shrubs											
Ilex glabra	99.8	114.4	117.4	105.6	93.3	44.8	48.4	6.2	**		
Lyonia ferruginea	3.6	2.2	2.1	.2	1.3	.0	1.3	.0			
Myrica spp.	.0	1.1	.0	.0	1.2	2.3	.0	.0			
Quercus minima	20.5	15.2	3.2	12.3	11.3	7.0	5.6	4.2			
Rubus spp.	.0	.0	.8	.1	.1	.5	.1	.0			
Serenoa repens	214.8	327.6	530.6	108.6	86.2	1.3	114.3	2.0	*	*	
Vaccinium spp.	25.0	30.0	6.6	20.3	21.4	17.2	27.4	8.0			
Other shrubs and vines	.0	.9	.1	4.5	.5	.0	.0	.0			
Total Shrubs	363.7	491.4	660.8	251.6	215.3	73.1	197.1	20.4	*		

[1] *Aristida spiciformis* was combined with *Sporobolus curtissii* in this measurement.
[2] *Paspalum* was combined with *Panicum* in this measurement.
[3] *, ** - denote statistical significance at the 0.05 and 0.01 levels of probability, respectively.

Table 3.--Frequency of understory vegetation before and 2 years after site preparation

Plant	No treatment (control)		Burn only (burn)		Burn+disk (disk)		Burn+disk+bed (bed)		Significance[3]		
	1970	1972	1970	1972	1970	1972	1970	1972	Treatment (1972)	Year	Treatment x year
	Percent										
Grasses											
Andropogon spp.	18	23	28	25	30	26	44	20			
Aristida spiciformis	(1)	3	(1)	6	(1)	11	(1)	6			
Aristida stricta	13	13	11	14	11	5	12	2			
Panicum spp.	14	10	9	35	22	92	23	96	**	**	**
Paspalum spp.	(2)	1	(2)	1	(2)	3	(2)	5			
Sporobolus curtissii	59	56	60	56	65	15	42	4		**	**
Other grasses	2	1	3	2	4	1	8	1			
Sedges	1	1	1	5	1	5	1	3			
Rushes	0	2	0	9	0	11	0	7		**	
Mosses	6	8	7	7	11	0	10	0	**		*
Forbs											
Compositae	8	9	13	11	16	13	18	6			
Leguminosae	0	0	0	3	0	1	0	0		**	
Xyris spp.	0	2	1	4	1	32	2	35	**	*	*
Other forbs	6	3	4	12	2	9	2	11		**	
Total Herbs									**	*	
Shrubs											
Ilex glabra	26	28	34	27	34	16	21	5			
Lyonia ferruginea	1	1	1	1	2	1	1	0		**	
Myrica spp.	0	1	1	1	2	1	0	0			**
Quercus minima	13	14	5	7	9	3	10	1	**	*	**
Rubus spp.	0	0	0	0	1	1	0	0			
Serenoa repens	22	25	27	21	24	2	22	2	*	**	**
Vaccinium spp.	18	24	17	26	13	10	19	6	**	*	**
Other shrubs and vines	1	1	0	1	1	0	1	0			
Total Shrubs									**	**	*

[1] *Aristida spiciformis* was combined with *Sporobolus curtissii* in this measurement.

[2] *Paspalum* was combined with *Panicum* in this measurement.

[3] *, ** - denote statistical significance at the 0.05 and 0.01 levels of probability, respectively.

Burning consumed much of the above-ground material. Two years after burning, the dry weight of all herbs was essentially the same as before burning, but dry weight of the shrubs was less than one-half the pretreatment level. The loss in shrub weight was attributable entirely to saw-palmetto. The change computed for this species may have been caused more by poor sampling than by actual decline. The dry weight of other shrubs was as large or larger than before burning. Rapid recovery was expected because these species evolved with fire and quickly resprout following a fire (fig. 2).

Figure 2.--Burn-only plot 2 years after burn. Note the lush growth of gallberry and saw-palmetto.

Intensive site preparation (disk or bed) killed nearly all vegetation. Two years later, however, both the disked and bedded plots were almost completely covered by a dense mat of panicum grasses (Panicum spp.) (fig. 3) and Xyris spp., which were much more numerous than before treatment (tables 2, 3, and 4). Site preparation increased the density of Xyris more than 300 times over the control. Xyris and rushes were especially prominent in the shallow furrows alongside each bed and in the depressions formed by disking. Other dramatic effects of site preparation were significant reductions in frequency, density, and dry weight of saw-palmetto, gallberry, and Curtiss dropseed (Sporobolus curtissii) on disked and especially on bedded plots. The average weight of saw-palmetto on disked and bedded plots was only 2 percent as great 2 years after treatment as before treatment. The total dry weight of shrubs (20.4 g/m^2) 2 years after bedding was only 6 percent as great as the average pretreatment dry weight for all plots.

MICROCLIMATE

Insolation and air temperature.--Incoming solar energy ranged from a minimum of 243 langleys per day in December 1971 to a maximum of 555 langleys per day in May 1973 (fig. 4). The minimum incoming radiation was in

Figure 3.--Burn+disk+bed treatment 2 years after preparation. Beds are covered with Panicums. Although the furrows appear to be bare, many small Xyris plants occupy this microsite.

December, and the maximum was in May of each year. Similarly, mean monthly maximum temperatures 23 cm above ground were lowest in January or February and highest in June or July of each year (fig. 5). Temperature changes near the ground lagged 1 to 2 months behind changes in incoming energy, but the same seasonal trends were evident.

Maximum and minimum temperatures at 23 cm were always more extreme than at 44 cm. The greatest diurnal temperature fluctuations occur at the soil-air interface and gradually diminish with distance above ground (Geiger 1959).

Site preparation altered temperatures 23 cm above ground (fig. 5). Temperatures on disked plots closely followed those on bedded plots. Control plots usually had minimum temperatures $\frac{1}{2}°$ to 2° below the intensive treatments, while burned plots were intermediate. Extreme diurnal air temperatures (-14° and 46° C) were recorded on control plots. Temperatures under the adjacent longleaf stand were similar to the control and indicate that a sparse stand of trees (BA of 10-14 m^2/ha) does not greatly alter incoming solar radiation. Site preparation altered air temperature near the ground mainly because it removed vegetation, which increased the solar radiation reaching the soil surface and increased wind movement and the subsequent mixing of air near the ground. In fact, incoming solar radiation at 2 cm above the ground level averaged 33 and 44 percent higher for disking and bedding, respectively, than for the control during the first 2 years after site preparation.

Table 4.--Effect of site preparation on density of vegetation 2 years after site treatment (1972)

Plant	No treatment (control)	Burn only (burn)	Burn+disk (disk)	Burn+disk+bed (bed)	Significance of treatment[1]
	- - - - - - - Number per square meter - - - - - - -				
Grasses					
Andropogon spp.	21.3	31.0	31.8	23.3	
Aristida spiciformis	1.3	13.2	7.5	6.8	
Aristida stricta	2.9	2.2	.2	.4	
Panicum spp.	6.2	43.2	104.7	100.7	**
Paspalum spp.	.1	.6	3.6	2.8	
Sporobolus curtissii	15.3	11.6	3.1	.8	*
Other grasses	1.7	4.3	33.7	13.6	
Sedges	2.4	4.9	1.8	3.6	
Rushes	1.3	4.5	4.5	5.9	*
Mosses	4.4	2.9	4.7	.8	
Forbs					
Compositae	12.0	16.5	17.7	8.0	
Leguminosae	.3	1.6	.4	.4	
Xyris spp.	.9	4.8	362.1	310.7	**
Other forbs	2.7	16.8	24.2	17.2	
Total Herbs	72.8	158.1	600.0	495.0	**
Shrubs					
Ilex glabra	19.4	23.1	13.8	3.4	**
Lyonia ferruginea	.8	.1	.1	.0	
Myrica spp.	.1	.0	.3	.0	
Quercus minima	16.7	8.2	3.2	2.2	
Rubus spp.	.0	.5	1.1	.0	
Serenoa repens	3.2	2.7	.2	.6	*
Vaccinium spp.	25.2	26.0	12.3	9.6	
Other shrubs and vines	.1	1.5	.0	.0	
Total Shrubs	65.5	62.1	31.0	15.8	**

[1] *, ** - denote statistical significance at the 0.05 and 0.01 levels of probability, respectively.

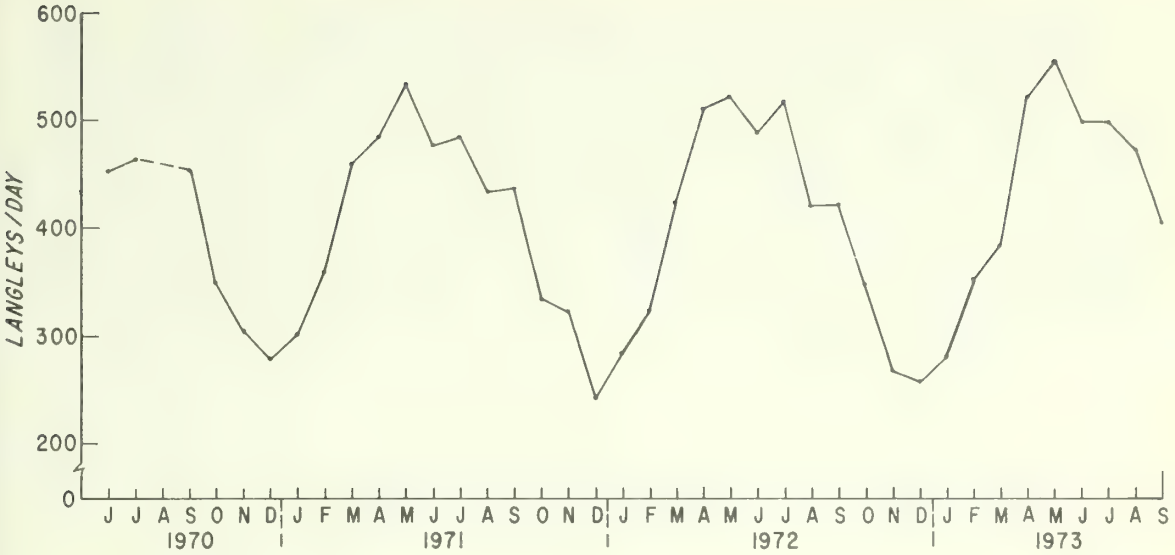

Figure 4.--Seasonal variation in solar radiation 90 cm above ground.

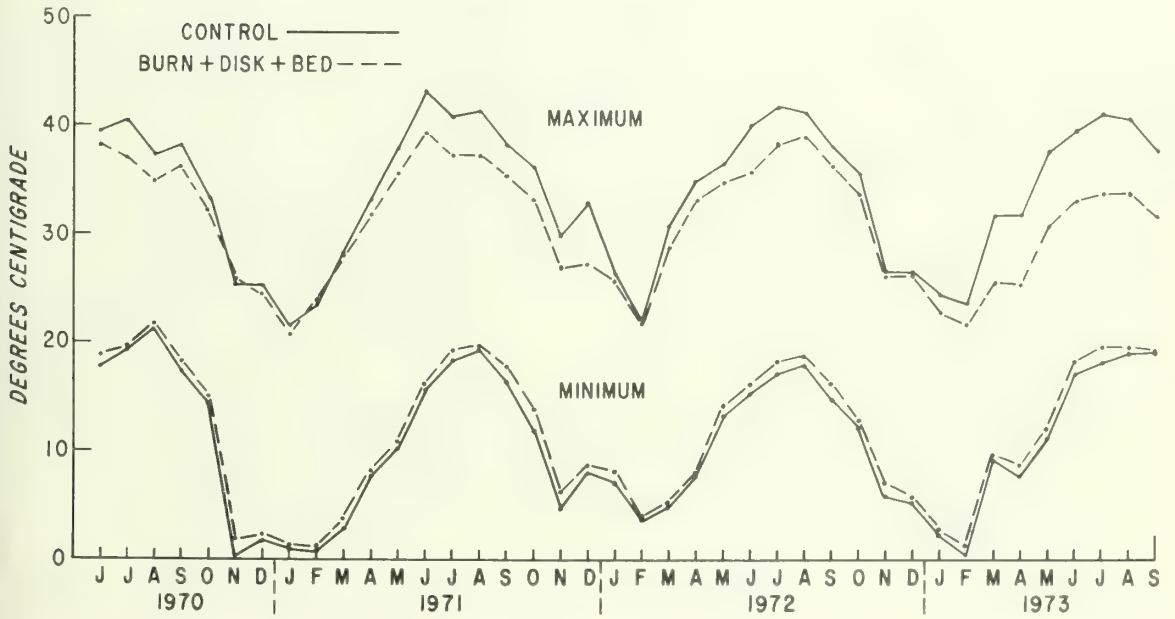

Figure 5.--Seasonal variation in maximum-minimum temperatures 23 cm above ground. Values are monthly averages derived from daily extremes.

Wind movement.--Site preparation greatly increased wind movement 50 cm above the normal ground line (fig. 6). Average weekly windspeed from June 1970 through September 1973 ranged from 0.22 to 1.23 m/sec for disking and from 0.13 to 0.79 m/sec for the control. Highest weekly and monthly windspeeds were recorded in late winter or spring of each year. Windspeed over disked plots was twice that of the control for the first year after treatment. Two years after site preparation, there was very little difference in windspeed between these two treatments. Bedded plots had substantially greater wind movement than other treatments even at the end of the study. Windspeed under the sparse longleaf stand adjacent to the study was not greatly different than for the control.

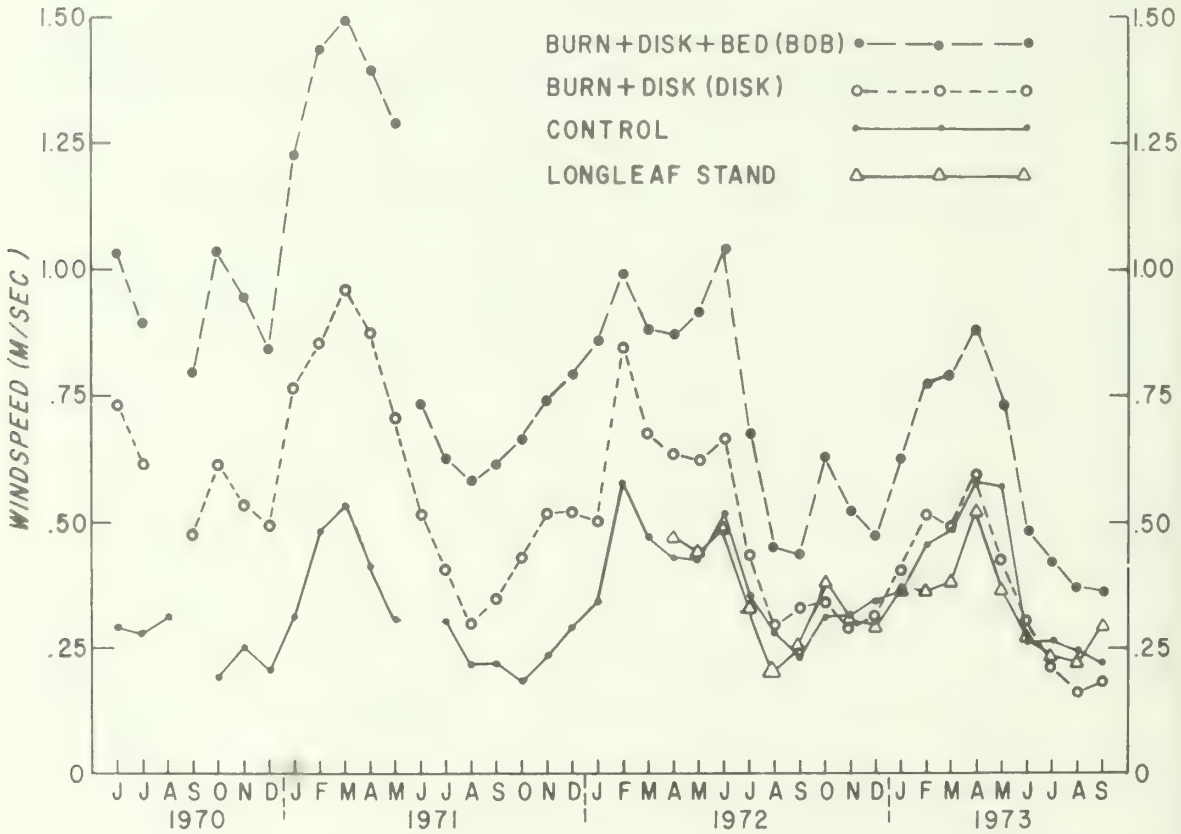

Figure 6.--Seasonal variation in windspeed as related to site preparation. Anemometers 50 cm above ground. BDB measurements were at 150 cm from June 1970 to May 1971.

Precipitation.--Rainfall totaled 84 cm during the last 6 months of 1970, 127 cm during 1971, 123 cm during 1972, and 141 cm during the first 9 months of 1973 (fig. 7). Summer months were the wettest each year; March, April, October, and November were the driest.

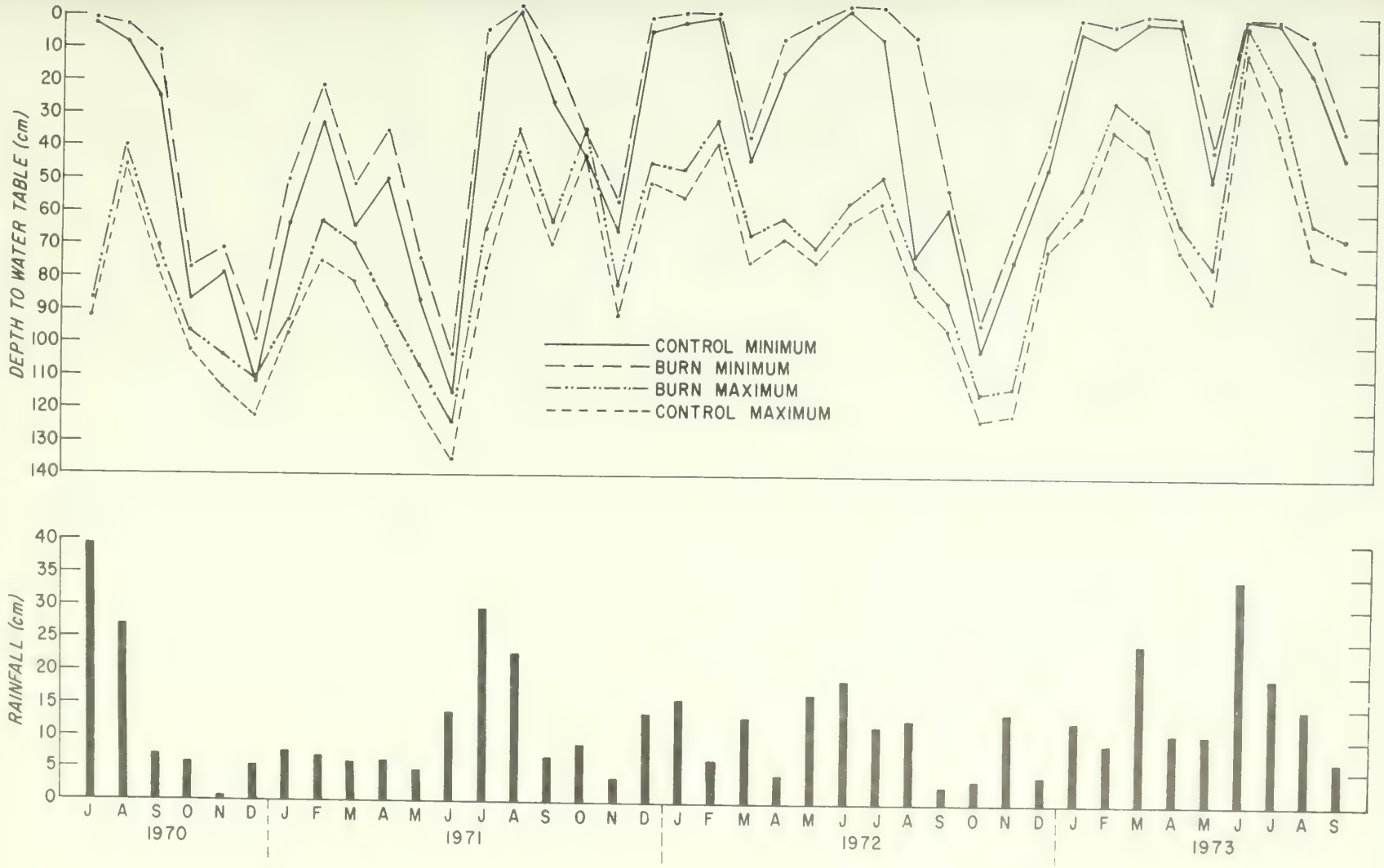

Figure 7. --Monthly rainfall and monthly water table depths for control and burn.

Soil moisture.--Water table levels fluctuated greatly during the study period and closely followed rainfall (fig. 7). The water table was at or above ground on seven occasions and was within 10 cm of the soil surface for approximately 20 percent of the study period. At the other extreme, water levels went below 100 cm for periods of 4 to 6 weeks on only three occasions during the study. Within a period of 7 weeks during July and August 1971, the water table went from a depth of 125 cm to slightly above the ground surface; it subjected newly planted seedlings to severe moisture stress quickly followed by reduced aeration owing to excess moisture.

The control plots always had the lowest water tables, while burned plots had the highest (fig. 7). This difference ranged from 2.5 cm during wet periods to 16 cm during dry periods. Disked and bedded plots had almost identical water table levels which averaged 1 to 2 cm above the control.

The most intensive cultural treatment (bedding) had the greatest number of measurement days (23 during a drought period of April to June 1971) in which there was no measurable soil moisture in the surface 7.5 cm. In contrast, disked plots had 8 and burned plots had 4 measurement days without available water in the surface 7.5 cm, while control plots had available water each day. This trend was caused by the vegetative cover. Excavation showed that within a year after treatment, both disked and bedded plots had a high concentration of herbaceous roots in the surface 15 cm but very few below this level. In severe droughts, evaporation plus transpiration quickly depletes the surface soil moisture. On control and burned plots shrub and herbaceous root systems were fairly well distributed throughout the surface 50 cm. Near the surface, roots were less concentrated on control than on disked or bedded plots. Thus, moisture was depleted to the permanent wilting point less rapidly on control plots.

Soil temperature.--At 2.5 cm below the soil surface, the maximum temperature increased with treatment intensity: control < burn < disk < bed (fig. 8). Maximum soil temperature under the nearby longleaf stand exceeded the control but was less than the burn treatment. Minimum temperatures were generally decreased by increasing the intensity of preparation (fig. 9). The differences in both maximum and minimum temperatures were greatest the first year after treatment.

On June 6, 1971, one year after site preparation, the maximum temperature at 2.5 cm below the surface at the top of a bed reached 51° C. At the same time, the temperatures in the disked, burned, longleaf stand, and control plots were 42°, 38°, 37°, and 28°, respectively. This example shows the value of plant cover in capturing radiation and shading the soil surface. Vegetative cover forms an absorption layer several decimeters thick in place of the infinitely thin absorption surface of bare ground.

At depths of 23 cm the differences between maximum and minimum temperatures were greater for beds than for other treatments. Annual changes in temperature were also greatest on beds. Burned plots had the highest soil temperatures at 23 cm during the first winter after treatment. The ability of ash to absorb heat rapidly explains this result.

Figure 8.--Seasonal variation in maximum soil temperature 2.5 cm below ground.

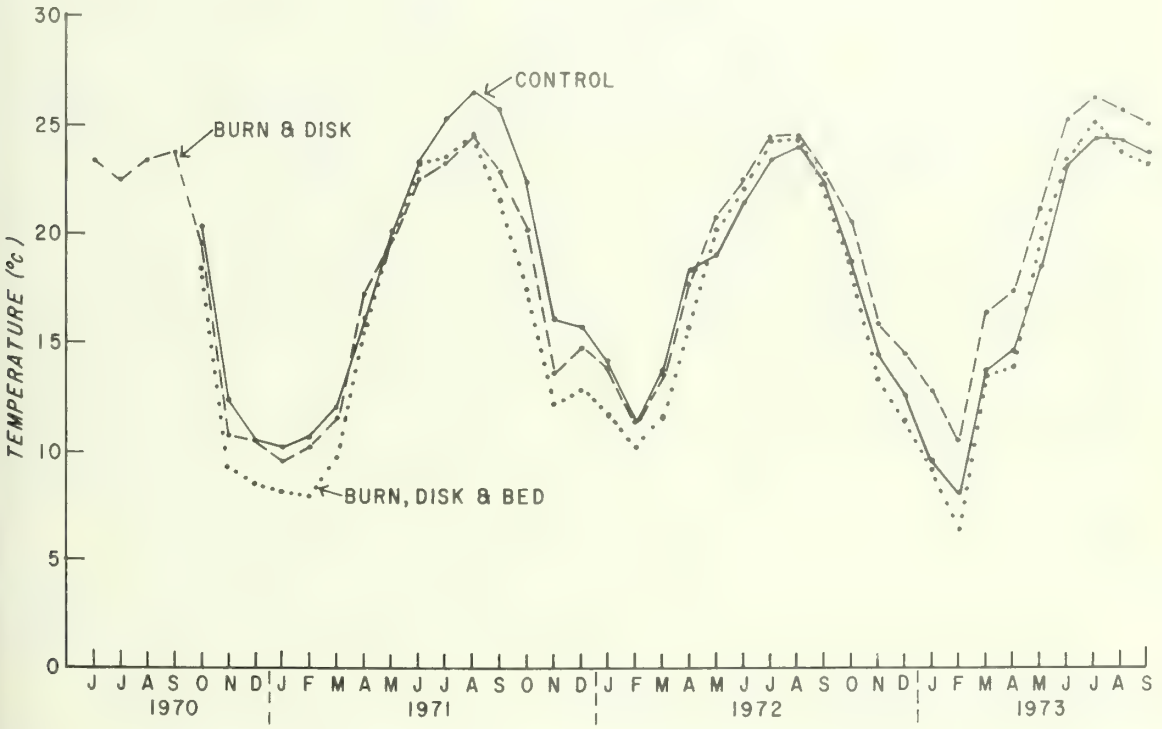

Figure 9.--Seasonal variation in minimum soil temperature 2.5 cm below ground.

TREE DEVELOPMENT

Four years after planting, commercial seedlings were significantly shorter (1.2 m) than superior stock (1.6 m). All 10 superior families were taller than commercial stock, and two families averaged 1.8 m tall. Site treatment significantly affected tree height which averaged 1.3, 1.1, 1.4, and 1.6 m for control, burn, disk, and bed, respectively. Site preparation did not significantly influence inherent growth rate.

First-year survival of superior seedlings was 82 percent, which was significantly better than the 65 percent attained by commercial seedlings. All trees were grown in the same nursery bed and were outplanted during a 4-day period immediately after a 6-cm rainfall. The small difference in survival 6 months after planting--83 percent survival for superior stock versus 77 percent for commercial stock--indicates that there was no difference in outplanting care. The 12-percent decrease in survival of commercial trees between 6 and 12 months after planting indicates that superior trees were better able to adapt and grow in the new environment. First-year survival for superior stock averaged 68 percent for control, 81 percent for burn, and 90 percent for both disk and bed. Survival of commercial stock was 55, 61, 70, and 72 percent for control, burn, disk, and bed, respectively.

Although tree survival and growth are generally increased by vegetation removal and intensive culture, pest problems often are increased (Miller 1972; Hertel and Benjamin, in press). Two of the most common insects which attack slash pine are tip moth (Rhyacionia spp.) and webworm (Tetralopha robustella Zell.). In this study, webworm attacks on tree seedlings were significantly higher in control plots (19 percent) than in other treatment plots (13 percent) only during the first year after treatment. A few trees were killed during the first year when several larvae combined to defoliate them. Tip moth damage was significantly higher in bedded plots than in the other three treatments during the second growing season and was significantly higher in both disked and bedded plots during the third year. Overall damage was low, ranging from 2 to 8 percent with no trees killed.

Rabbits clipped the tops out of 10 trees the first year but killed only one of them. Seven of the damaged trees were in burned plots.

CONCLUSIONS

Site preparation altered soil properties, vegetation, and microclimate. The most intensive treatment (bedding) consistently produced the greatest change.

Erosion following site preparation is almost nonexistent in the north Florida flatwoods, because slope is negligible and most of the surface soil is sand. Heavy rain shortly after bedding may wash some soil from beds back into the furrows (Schultz and Wilhite 1974). Within a few months after preparation, however, enough vegetation appears to halt soil movement, even from

bed to furrow. Furrows remain distinct until they become overgrown with vegetation. The undulations on bedded areas will remain for the entire tree rotation and will channel any overland water movement parallel to the beds. Thus, it is important that beds be constructed in the direction of normal drainage if they are to assist water removal during very wet periods.

The most striking result of disking or disking plus bedding was the reduction in frequency, density, and dry weight of saw-palmetto, gallberry, and Curtiss dropseed. Gallberry will rapidly reinvade the prepared sites within 4 to 5 years after treatment because it sprouts prolifically from roots and stems cut and buried by disking. Because Curtiss dropseed is a prolific seeder, it also will quickly reinvade. Saw-palmetto, however, reproduces and grows slowly, and it will not return to its pretreatment frequency, especially if soil scarification continues in successive rotations.

Site preparation also appeared to reduce the frequency, density, and dry weight of pineland threeawn (Aristida stricta Michx.). Although not statistically significant in our study, this trend has been noted by others (Hebb 1971; Univ. of Fla. 1972; Schultz and Wilhite 1974).

On a long-term basis, only saw-palmetto, and perhaps pineland threeawn to a lesser extent, is adversely affected by site preparation. Saw-palmetto competes vigorously with planted pines for nutrients throughout the year and for moisture during dry periods. We do not know how the loss of this species over broad areas might affect the natural flatwoods ecosystem.

Disking or bedding immediately changed the microclimate of the site. Temperature, light, and wind movement were greatly increased. The greatest change was in wind movement, which caused rapid evaporation.

Rapid invasion of beds by shallow-rooted panicum grasses reduced the temperature at the soil-air interface by keeping direct sunrays off the soil; but it also reduced moisture available for planted pines, especially in the surface 15 cm of the soil. Trees planted in unprepared areas must immediately compete with established vegetation for light, moisture, and nutrients. The significant increase in first-year tree survival after disking or bedding, when compared to the control, can be attributed to reducing vegetative competition during the first few months after planting.

Most periods of high water table or flooding occurred during the growing season. They probably slowed tree growth on all but the bedded areas. This, of course, is one of the primary reasons beds are formed on wet, flatwood areas (Langdon 1962; Schultz 1973; Mann and McGilvray 1974).

Bedding cannot increase the fertility of a site. It does, however, concentrate nutrients by pulling relatively rich surface soil from furrowed strips onto the beds. Bedding thus puts newly planted seedlings close to additional nutrients for the first few years. During the remainder of a tree rotation, tree roots will proliferate and utilize nutrients throughout the soil mass, regardless of treatment, unless poor aeration or competition with other vegetation are limiting factors.

Trees growing on burned plots were shorter than those in any other treated plot. The normal procedure is to burn just before planting to give newly planted seedlings a chance to become established before competing vegetation grows back. In this study, since the burned plots were not planted for nearly a year after treatment, the value of burning was lost. Rapidly growing vegetation may have proved more severe competition on burned than on control plots.

Four-year-old slash pine trees growing on beds were only 0.2 m taller than trees on disked plots. This relatively small difference suggests that bedding may not be superior to disking for pine growth on many flatwood sites. In fact, in a 14-year study in north Florida average tree volume of slash pines growing on beds was no greater than for trees growing on disked areas. However, bedding increased volume per acre by 270 cubic feet over disking because it increased survival by 15 percent (Schultz 1975). An increase in tree survival on wet flatwoods, therefore, may be the most important benefit of bedding.

The effects of bedding should be closely monitored over a wide range of flatwoods sites and with many genotypes. We must ascertain both its value in terms of yields and the potential problems which may arise because of altered drainage and changes in vegetation. The development of slash or loblolly pine genotypes that are especially suited to wet conditions may reduce the need for bedding.

Significant increases in tip moth damage following disking or bedding indicate that vegetative cover is valuable for hiding pine seedlings from this insect. Tip moth damage can severely retard seedling growth but usually does not kill trees. Once trees grow above competing vegetative cover on untreated plots, they are just as susceptible to the tip moth as trees on prepared plots. Absence of site preparation is only a short-term advantage. Webworm larvae feed more actively on the needles of seedlings that are surrounded by other vegetation. Although webworm can slow the growth of newly planted seedlings, it rarely causes sufficient defoliation to kill trees. It is not an important factor after the first growing season because the leaf surface area of seedlings is increased by rapid growth.

LITERATURE CITED

Bray, R. H., and L. T. Kurtz
1945. The determination of total organic and available forms of phosphorus in soils. Soil Sci. 59:39-45.

Day, P. R.
1956. Report of the committee on physical analyses, 1954-1955. Soil Sci. Soc. Am. Proc. 20:167-169.

Geiger, R.
1959. The climate near the ground. 494 p. Harvard Univ. Press. Cambridge, Mass.

Haines, L. W., and W. L. Pritchett
1965. The effects of site preparation on the availability of soil nutrients and on slash pine growth. Soil & Crop Sci. Soc. Fla. Proc. 25:356-364.

Hebb, E. A.
1971. Site preparation decreases game food plants in Florida sandhills. J. Wildl. Manage. 35:155-162.

Hertel, G. D., and D. M. Benjamin
[In press.] Intensity of site preparation influences pine webworm and tip moth infestations of pine seedlings in north-central Florida. Environ. Entomol.

Humphreys, F. R., and W. L. Pritchett
1971. Phosphorus absorption and movement in some sandy forest soils. Soil Sci. Soc. Am. Proc. 35:495-500.

Langdon, O. G.
1962. Ridge planting improves early growth of South Florida slash pine. J. For. 60:487.

Lewis, C. E.
1970. Responses to chopping and rock phosphate on south Florida ranges. J. Range Manage. 23:276-282.

McMinn, J. W.
1969. Preparing sites for pine plantings in south Florida. USDA For. Serv. Res. Note SE-117, 5 p. Southeast. For. Exp. Stn., Asheville, N.C.

Mann, W. F., Jr., and J. M. McGilvray
1974. Response of slash pine to bedding and phosphorus application in southeastern flatwoods. USDA For. Serv. Res. Pap. SO-99, 9 p. South. For. Exp. Stn., New Orleans, La.

Miller, T.
1972. Fusiform rust in planted slash pines: influence of site preparation and spacing. For. Sci. 18:70-75.

Schultz, R. P.
1973. Site treatment and planting method alter root development of slash pine. USDA For. Serv. Res. Pap. SE-109, 11 p. Southeast. For. Exp. Stn., Asheville, N.C.

Schultz, R. P.
1975. Managing genetically improved southern pines, p. 209-237. In Forest tree improvment--the third decade. 24th La. State Univ. Symp., Baton Rouge.

Schultz, R. P., and L. P. Wilhite
1974. Changes in a flatwoods site following intensive preparation. For. Sci. 20:230-237.

University of Florida
1972. Cooperative research in forest fertilization: annual report. Univ. Fla., Inst. Food & Agric. Sci., 16 p.

Worst, R. H.
1964. A study of effects of site preparation and spacing on planted slash pine in the Coastal Plain of southeast Georgia. J. For. 62:556-560.

Schultz, Robert P.
1976. Environmental change after site preparation and slash pine planting on a flatwoods site. USDA For. Serv. Res. Pap. SE-156, 20 p. Southeast. For. Exp. Stn., Asheville, N.C.

On a flatwoods site in north Florida, mechanical site preparation greatly reduced the frequency, density, and dry weight of most shrubs and changed the predominant vegetation from Serenoa repens, Ilex glabra, and Sporobolus curtissii to Panicum spp. and Xyris spp. Bedding produced adverse temperature, moisture, insolation, and wind effects. Early slash pine survival was significantly improved by mechanical site preparation, and superior trees grew significantly faster than commercial stock. By age 4, trees growing on beds averaged only 0.3 m taller than trees growing without the benefit of site preparation.

Keywords: Site treatment, Pinus elliottii Engelm., vegetation change, soil properties.

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A 13.79:SE-157

USDA Forest Service Research Paper SE-157 February 1977

Particleboard Production, Markets, and Raw Material Requirements in the South

by

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ACKNOWLEDGMENTS

I thank Mr. Charles Morschauser, Technical Director, National Particleboard Association, for his advice and assistance in all phases of this study. I also appreciate the cooperation of the particleboard plant managers and other corporate officials who provided the information basic to the success of the study.

Particleboard Production, Markets, and Raw Material Requirements in the South

by

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Abstract. --Responses to a mailed questionnaire by 25 southern particleboard plants show that approximately 40 percent of 1973 particleboard manufactured in the South was intended as floor underlayment. An additional 22 percent was intended for mobile home decking, and most of the rest was for various types of core stock. With the heavy emphasis on the manufacture of floor underlayment and mobile home decking, the industry was in a vulnerable position when the housing industry slumped in 1974.

Southwide, the industry required an average of 1.5 tons of wood raw material (dry-weight basis) for each thousand square feet (3/4-inch basis) of particleboard manufactured. Slightly more than 90 percent of this particleboard was of medium density. Wood residues were the favored raw material in most plants. Planer shavings were most often used with lesser amounts of pulp-type chips, plywood mill waste, sawdust, slabs, edgings, or trimmings. Some plants used some roundwood but none used bark.

Keywords: Sawmill residues, residue use.

Particleboard production in the South increased from 236,601,000 square feet (3/4-inch basis) in 1964[1] to 1,372,853,000 square feet in 1974.[2] The South accounted for 44 percent of all particleboard manufactured in the United States in 1974.[2] This rapid expansion led the USDA Forest Service to survey production and raw material needs of all southern particleboard plants. The survey was based on 1973 operations. Herein are summarized the findings of the survey.

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[1]U.S. Department of Commerce, Bureau of Census. 1967. Particleboard 1965. Curr. Ind. Rep. Ser. MA-24L (65)-1. 3 p.

[2]U.S. Department of Commerce, Bureau of Census. 1975. Particleboard 1974. Curr. Ind. Rep. Ser. MA-24L (74)-1. 5 p.

THE SURVEY

In late 1974, a questionnaire was mailed to the 37 southern particleboard plants listed in the directory of plants in the July issue of Forest Industries or reported by the National Particleboard Association. Plants were asked to report 1973 production and raw material use. Questionnaire responses and followup telephone calls revealed that 33 southern plants were manufacturing particleboard. Plants that produced medium density fiberboard or thin panelboard were excluded.

A second questionnaire was mailed to plants that did not return the first. Twenty-five of the 33 operating plants responded to the questionnaires.

PRODUCTION

Respondents produced 1,382,956,000 square feet (3/4-inch basis) of particleboard in 1973. For the South, the Bureau of the Census tallied a total for all plants of 1,567,343,300 square feet (3/4-inch basis).[2] Thus, our responding plants accounted for 88 percent of all southern particleboard production.

The platenboard process dominates the industry. Platenboard production was 1,360,563,000 square feet (3/4-inch basis) while that of extruded board was only 22,393,000 square feet.

Southwide hourly production per plant averaged 7,401 square feet (3/4-inch basis). The plants operated an average of 320 days a year, usually for three shifts a day.

PARTICLEBOARD MARKETS

Each plant was asked to estimate the percentages of its annual output going to typical markets for particleboard. Floor underlayment accounted for 40 percent of all board manufactured. Mobile home decking ranked second among board uses reported and accounted for 22 percent of southwide production (table 1). While many plants produced board for more than one market, many plants produced either or both of these types of floor decking. Heavy dependence on the residential construction market left many plants vulnerable when the housing market dipped sharply in 1974.

As compared with the nationwide mix of particleboard items, southern plants produce relatively little board for core stock in furniture and the like (table 1). Although furniture manufacturing plants are concentrated in some areas of the Southeast, especially in North Carolina,[3] the southern particleboard is used

[3]U.S. Department of Commerce, Bureau of Census. 1975. Census of manufacturers, 1972. Subject Series: Gen. Summ., MC 72 (1)-1. 327 p.

Table 1.--Percent of plants in Southern United States producing particleboard for selected markets and percent of production by end use for the South and the United States, 1973

Intended market	Percent of plants	Percent of total production	
		South	United States
Mobile home decking	40	22	15
Factory-built housing decking	([1])	([2])	([2])
Floor underlayment	56	40	27
General-purpose core stock	28	9	10
Furniture core	56	20	27
Cabinets	24	3	4
General-purpose core stock, furniture and core cabinets	0	0	8
Siding	0	0	1
Door core	12	3	4
Other	12	3	4
Total	([3])	100	100

[1] Information omitted to avoid disclosure.
[2] Less than one-half of one percent.
[3] Total is more than 100 percent because many plants manufacture particleboard intended for several different markets.

mainly in mobile homes made in the South and residential construction in the South and Northeast. Many of the large integrated companies in the South have traditionally emphasized the construction market. Their distribution system is oriented to this market, perhaps to the exclusion of other opportunities. Another factor influencing the product mix of southern particleboard plants is the ease with which high-quality industrial particleboard can be manufactured from western wood species and thus the preference by many industrial users for particleboard manufactured in the West.[4]

BOARD DENSITY

Low-density particleboard (less than 37 pounds per cubic foot) was produced by only a few respondents and amounted to less than 2 percent of all production in the South. These plants also produced medium-density board. Most of the door core was made in plants that produced low-density board.

[4] Withycombe, Richard. 1975. The outlook for particleboard manufacture in the Northern Rocky Mountain Region. USDA For. Serv. Gen. Tech. Rep. INT-21, 39 p. Intermt. For. & Range Exp. Stn., Ogden, Utah.

Medium-density particleboard (37 to 50 pounds per cubic foot) was manufactured by virtually every plant. Approximately 70 percent of these plants produced only medium-density board. Ninety-one percent of all board reported was medium density.

High-density particleboard (over 50 pounds per cubic foot) was produced by only six of the platenboard plants. All of them produced medium-density board as well. Only about 7 percent of all board reported was high density. No particular pattern of product use for this board density was discerned.

NEW PRODUCTS

Plant managers were asked if they had begun the manufacture of any new particleboard item during 1973 or if any new products were planned for their plants by 1978. Only five managers cited any type of change. Most changes were not new to the industry; rather, they were standard products new to that particular plant.

The small number of comments about new products could be attributed to several factors. Many plants are part of large integrated forest products corporations in which decisions about new products may be made by higher executives than those responding to the questionnaire. In most large corporations, new products could be planned for production at new plant sites. Finally, the economic climate at the time of the survey was poor. Many particleboard producers were concerned with poor conditions in almost all markets and were thus not interested in trying an unproven product.

Structural particleboard was not mentioned as a potential new product, even though considerable effort and money are being invested in developing this type of board by several public and private research organizations. Companies may be considering building new plants to manufacture this product.

Interior decorative paneling was manufactured in small quantities by just a few plants. But the rapidly developing technology and markets for both wall paneling and cabinets appear to raise the prospects for some type of prefinished particleboard.

RAW MATERIALS

Because of wide variations in raw material purchasing and record keeping, an extensive telephone followup was used to determine wood raw material requirements of the southern particleboard industry.

Results show that 1.5 tons of wood (dry-weight basis) are required for each thousand square feet (3/4-inch basis) of particleboard produced. All plants used at least 1 ton (dry-weight basis) of wood per thousand square feet of finished board (3/4-inch basis), while one plant, a producer of high-density board, used slightly over 2 tons per thousand square feet. There was relatively little variation among plants producing medium-density board.

The industry uses wood in a variety of forms (table 2). Planer shavings are the preferred form. Plywood mill waste, sawdust, and pulp-type chips are also often used. Not all raw material in 1973 was plant residues. Approximately 11 percent of the industry requirements were met by roundwood.

Table 2.--Tons and percent of raw materials used by particleboard industry in the South and percent used in the United States, 1973

Type of raw material	Tons used in South (Dry-weight basis)	Percent used	
		South	United States
Roundwood	226,954	11	7
Veneer core	(1)	(1)	(2)
Planer shavings	1,274,651	61	65
Plywood mill waste	239,098	11	10
Slabs, edgings, and trimmings	49,044	2	3
Sawdust	191,674	9	9
Chips	84,911	4	5
Bark	0	0	0
Other	(1)	(1)	1
Total	2,099,611	100	100

[1]Data withheld to avoid disclosure.
[2]Less than one-half of one percent.

Individual plants often used a combination of furnish (table 3). Many plants used pulp-type chips, sawdust, and plywood mill waste in addition to planer shavings. Chips were used by more plants in the South than nationwide, but chips accounted for only a small amount of the total volume of furnish either in the South or nationwide (tables 2 and 3). This more frequent southern usage of chips is probably explained by their availability from small log processing and numerous chip-n-saw facilities in the region. Although the questionnaire included bark as a possible raw material, none was reported.

Table 3.--Percent of plants in the South and in the United States using different types of wood raw materials, 1973

Type of raw material	Percent of plants in	
	South[1]	United States[1]
Roundwood	12	9
Veneer core	(2)	4
Planer shavings	80	85
Plywood mill waste	44	40
Slabs, edgings, and trimmings	16	21
Sawdust	44	47
Chips	48	34
Bark	0	0
Other	(2)	6

[1] Total is more than 100 percent because many plants use more than one type of raw material.
[2] Data withheld to avoid disclosure.

SOFTWOOD AND HARDWOOD USE

Approximately 81 percent of the 2,099,611 tons of furnish required by southern manufacturers in 1973 consisted of softwood species; the remainder was hardwood. Nevertheless, approximately 76 percent of the plants used some hardwood. A half dozen plants used more hardwood than softwood.

RAW MATERIAL PROCUREMENT PROBLEMS

Plant managers were asked to describe any problems they had in obtaining wood during 1973. Only nine plants (36 percent) reported raw material procurement problems. Many of the comments were about winter weather conditions that slowed production at sawmills which were supplying the particleboard plants. Early in 1973, record rains and flooding occurred in Midsouth States and most of the South had very wet weather. Therefore, these supply problems were related to unusual weather conditions. Discounting the weather-related difficulties, particleboard plants in the South had few wood raw material supply problems despite strong demand for particleboard through the first three quarters of 1973.

ANTICIPATED RAW MATERIAL TRENDS

Ten managers (40 percent of the respondents) said they planned some type of change in their raw material mix or procurement method. The most frequently mentioned changes were use of more sawdust or more hardwood. A few

anticipated using more planer shavings. Also mentioned was the addition of long roundwood and pulp-type chips to the present mix.

To obtain these additional or different raw materials, some managers said they would probably have to haul from greater distances. Others said their suppliers were burning more wood residue for fuel, thus putting the particleboard manufacturers in competition with the value of this material as an energy source.

Although several plants planned to change their raw material mix or procurement method, the supply outlook was generally good for southern particleboard plants. Plants in this region can be expected to diversify their raw material mix away from their relatively heavy preference for planer shavings. Also, more and more hardwood species will be used as an alternative to softwoods.

Dickerhoof, H. Edward
1977. Particleboard production, markets, and raw material requirements in the South. USDA For. Serv. Res. Pap. SE-157, 7 p. Southeast. For. Exp. Stn., Asheville, N.C.

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Front Cover.--Shope Fork in the fall during the low flow period. This oligotrophic stream drains 760 ha within the Coweeta Basin.

Fluctuations in Naturally Occurring Populations of Enteric Bacteria in Oligotrophic Streams of Western North Carolina[1]

by

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Abstract.--In mountain streams of western North Carolina, naturally occurring populations of enteric bacteria fluctuated seasonally and diurnally. Seasonal fluctuations in total coliforms and fecal coliforms were apparently regulated by water temperature. Diurnal fluctuations in total coliforms were inversely related to daily cycles in streamflow. Total and fecal coliforms and fecal streptococci peaked during stormflows. These fluctuations complicate the assessment of water quality and should be considered in designs for stream sampling.

Keywords: Heterotrophic, diurnal cycles, stream discharge, stream nutrient content, turbidity.

Streams and lakes on National Forests and other forested and recreational areas are periodically monitored for water quality and closed to the public if pollution reaches dangerous levels. Land managers responsible for water sampling and interpretation of water quality standards on these areas need a better understanding of naturally occurring populations of enteric or intestinal bacteria in streams. Assessment of the impact of man's activities on water quality is complicated by these naturally occurring or baseline populations because coliform bacteria from natural sources may exist in substantial numbers in the absence of human activity (Hanes and others 1965). In this Paper, we describe baseline populations of enteric bacteria in oligotrophic streams (high in dissolved oxygen and low in plant nutrients) of western North

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[1] Contribution No. 223 from the Eastern Deciduous Forest Biome, US-IBP. Research supported in part by the USDA Forest Service, Southeastern Forest Experiment Station, Franklin, N. C., and in part by the Eastern Deciduous Forest Biome, US-IBP, funded by the National Science Foundation under Interagency Agreement AG-199, BMS 69-01147 A09 with the Energy Research and Development Administration--Oak Ridge National Laboratory.

Carolina and the seasonal and diurnal fluctuations of these populations during storm and nonstorm periods.

SAMPLING SITES AND METHODS

Streams were sampled at and near the Coweeta Hydrologic Laboratory in the mountains of southwestern North Carolina. This 2,270-ha basin varies in elevation from 685 to 1,600 m. The climate is marine with cool summers, mild winters, and adequate rainfall in all seasons. Average annual precipitation varies from 170 cm at the lowest elevations to 250 cm at the highest elevation. Snow typically comprises less than 5 percent of the annual precipitation. There is virtually no overland flow from the forest, and quickflow is usually less than 10 percent of the total flow (Hewlett and Hibbert 1965).

The primary sampling site at Coweeta was Shope Fork (front cover), one of the two oligotrophic streams that drain the basin. Shope Fork, which is generally free of human activity, drains 760 ha and has a mean daily flow of 36 liters/second/km^2(3.29 ft^3/second/mi^2). Supplementary data were taken from Ball Creek, which drains the other portion of the Coweeta basin. Samples from both streams were collected immediately above the weir ponding basins. Shope Fork was sampled at 1400 hours every Wednesday from late August 1972 through the first week in November 1973, and Ball Creek was sampled every sixth week during the same period. Both streams were also intensively sampled each season at approximately 3-hour intervals during storm and nonstorm periods.

All samples were collected in pre-sterilized, wide-mouth bottles fitted with ground-glass stoppers and aluminum foil hoods. These samples were taken from the flowing portion of the streams at a depth sufficient to exclude surface scum without introducing bottom sediment. After collection, the samples were returned to the laboratory and processed within 30 to 45 minutes. Time, stream temperature and stage, amount of dissolved oxygen, and general climatic conditions were recorded. Chemical analysis of selected water samples included pH, NO_3-N, NH_4-N, PO_4^{-}, Cl^{-}, K^{+}, Na^{+}, Ca^{++}, and Mg^{++}. Anions were determined with a Technicon AutoAnalyser®[2] and cations by atomic absorption. Precipitation was measured at a gage located 23 meters from the sampling site on Shope Fork, and streamflow for Shope Fork was measured at the stream's gaging station.

Counts of total and fecal coliforms and fecal streptococci were determined for all samples by the standard membrane filter technique (American Public Health Association 1971). Total coliforms were incubated at 35° C for 24 hours on M-Endo Media and fecal streptococci at 35° C for 48 hours on M-Enterococcus Agar.[3] Fecal coliforms were incubated in a water bath at 44.5° C for 24 hours on M-FC Broth. Three plates were prepared for each determination. The colonies on each plate were counted twice, and the six values were averaged.

[2] Technicon Corp., Tarrytown, N. Y. Mention of trade names in this Paper is for identification only and does not constitute endorsement by USDA.

[3] All media for this study were obtained from Becton, Dickinson and Company, Cockeysville, Md.

To assess the content of streams subject to human activity, we also sampled two streams near Standing Indian Campground, a 53-unit recreational area 9.7 km from Coweeta on the Nantahala National Forest. Samples were collected at 3-hour intervals for 48 consecutive hours over a 3-day period in mid-July 1973 while the campground was fully occupied. Kimsey Creek, which borders the campground, was sampled at points 1.6 km above and immediately below the camping area. The Nantahala River, which is fed by Kimsey Creek, was sampled at points 1.8 km above and 1.2 km downstream from the mouth of the creek. Total coliforms, fecal coliforms, and fecal streptococci were determined for both streams at each sampling period. A portable membrane filtration unit and incubator were used to process these samples in the field. No physical parameters of these streams were measured, but observations were made of human activities in the streams.

RESULTS

SEASONAL FLUCTUATIONS

The total coliform population at Shope Fork fluctuated considerably during the 14-month study period (fig. 1). This population was near zero in February, increased gradually throughout the spring, and averaged approximately 1,000/100 ml until September. Coincident with the onset of leaf fall, counts peaked at above 2,000/100 ml in late September of 1972 and 1973. The total coliform count decreased abruptly in mid-October in both years, coinciding with decreases in stream temperature from 13.0° C to 11.1° C in 1972 and from 14.5° C to 10.0° C in 1973. Samples taken during storm periods increased the mean total coliform count by factors as great as four during the fall, five during the summer, two during the spring, and one or less during the winter. The relative standard deviation for total coliforms by triplicate determinations was ±9.1 percent.

High ratios of fecal coliform to fecal streptococcus counts (FC/FS) usually indicate the presence of pollution (Geldreich 1966). In the present study, these ratios varied in an apparently random fashion from week to week during nonstorm periods and were consistently low. Seasonal fluctuations in these ratios during nonstorm periods were therefore considered insignificant. The relative standard deviations for fecal coliform and fecal streptococcus determinations were ±3.0 percent and ±4.9 percent.

Of the stream parameters routinely measured, only streamflow and stream temperature exhibited any correlation with seasonal counts of total coliforms. A weak inverse correlation with streamflow existed; that is, highest counts were obtained during the fall when flow was lowest and lowest counts were obtained during the winter when flow was highest. A stronger correlation existed between bacterial counts and stream temperatures recorded over the 14-month period. The plotting of total coliform counts vs. stream temperatures during nonstorm periods suggested a sigmoid relationship with a sharp increase in counts at temperatures near 11.0° C (fig. 2). These data were fitted by the equation

$$C = -859.47\,(T) + 87.72\,(T^2) - 2.39\,(T^3) + 2626.17$$

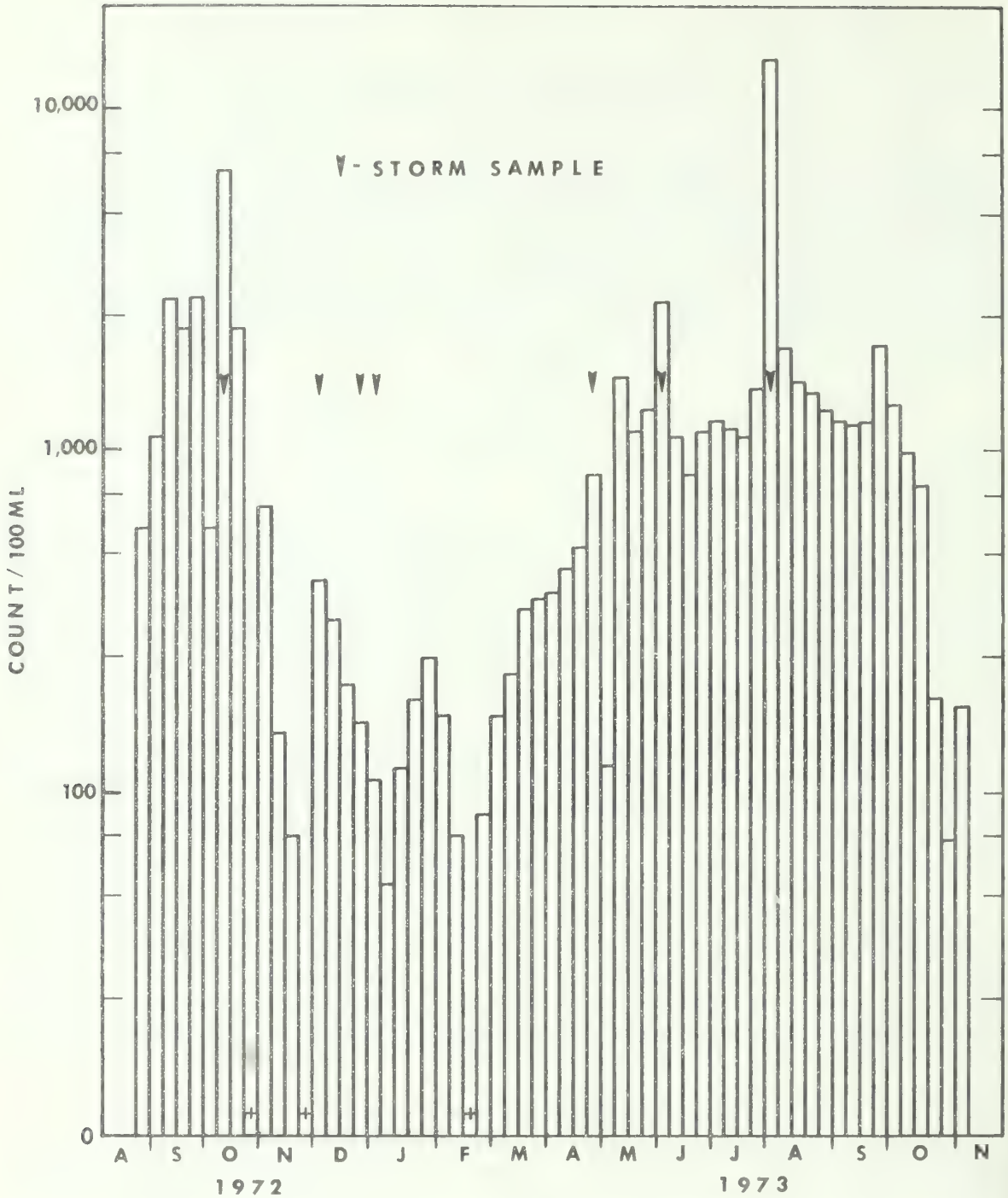

Figure 1.--Total coliform count for Shope Fork at weekly intervals from the last week in August 1972 through the first week in November 1973. The +'s indicate negligible counts. Sampling dates coinciding with storms are noted.

where C = total coliforms/100 ml and T = temperature in degrees Celsius ($R^2 = 0.79$). Samples taken from Ball Creek did not vary significantly from the Shope Fork results.

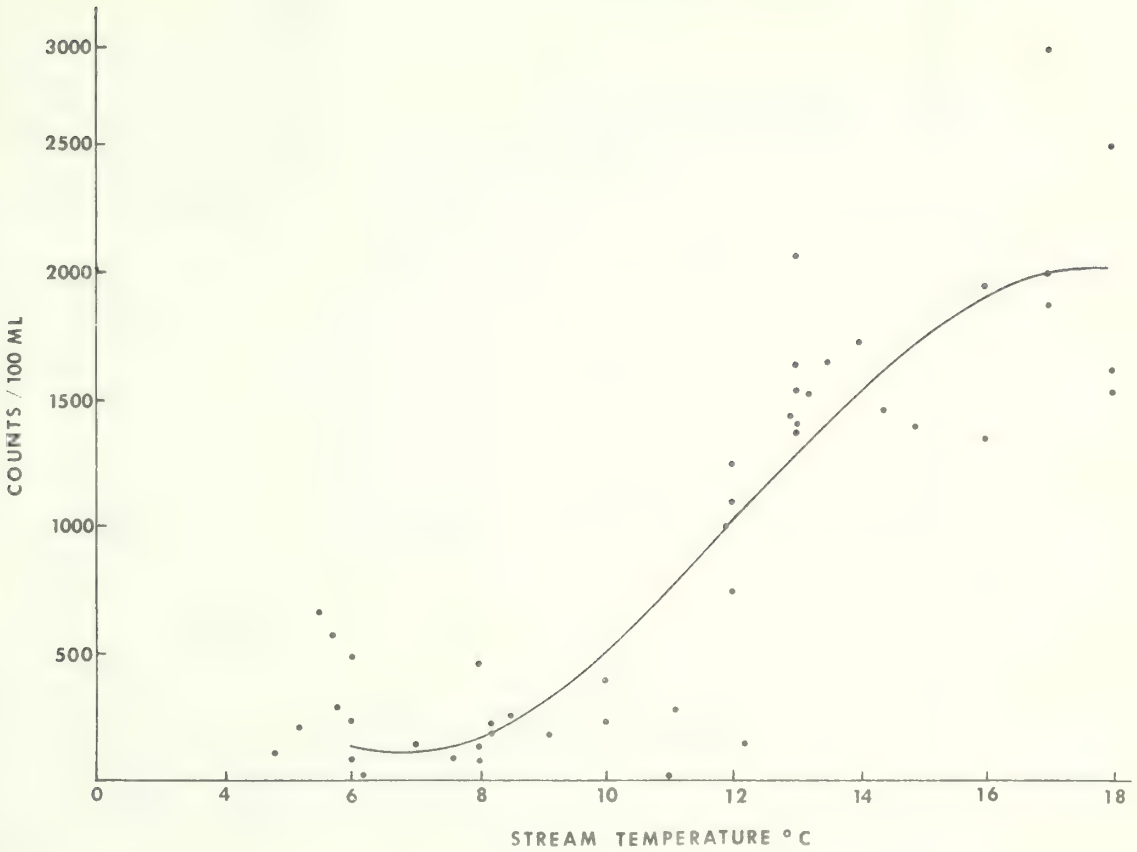

Figure 2.--The relationship between total coliforms during nonstorm periods and stream temperatures recorded over the 14-month study period at Shope Fork.

DIURNAL FLUCTUATIONS DURING NONSTORM PERIODS

Diurnal fluctuations in total coliform counts at Shope Fork were pronounced in the spring and fall and less pronounced in other seasons (fig. 3). Maximum counts usually occurred between 1130 and 1400 hours, and minimum counts usually occurred at night between 2400 and 0330. Diurnal fluctuations were least pronounced during winter, when there was a nearly flat response during the morning hours.

Of stream parameters measured throughout the day during nonstorm periods, the closest correlation was with daily streamflow patterns. During nonstorm periods, total coliform counts were inversely related to flow rate; that is, maximum counts always coincided with minimum flow (in the afternoon) and minimum counts always coincided with maximum flow (late at night). These daily patterns of baseflow are typical of streamflow records at the Coweeta Hydrologic Laboratory (Dunford and Fletcher 1947).

Total coliform counts were apparently unrelated to daily fluctuations in stream pH and inorganic nutrient levels, neither of which exhibited a consistent

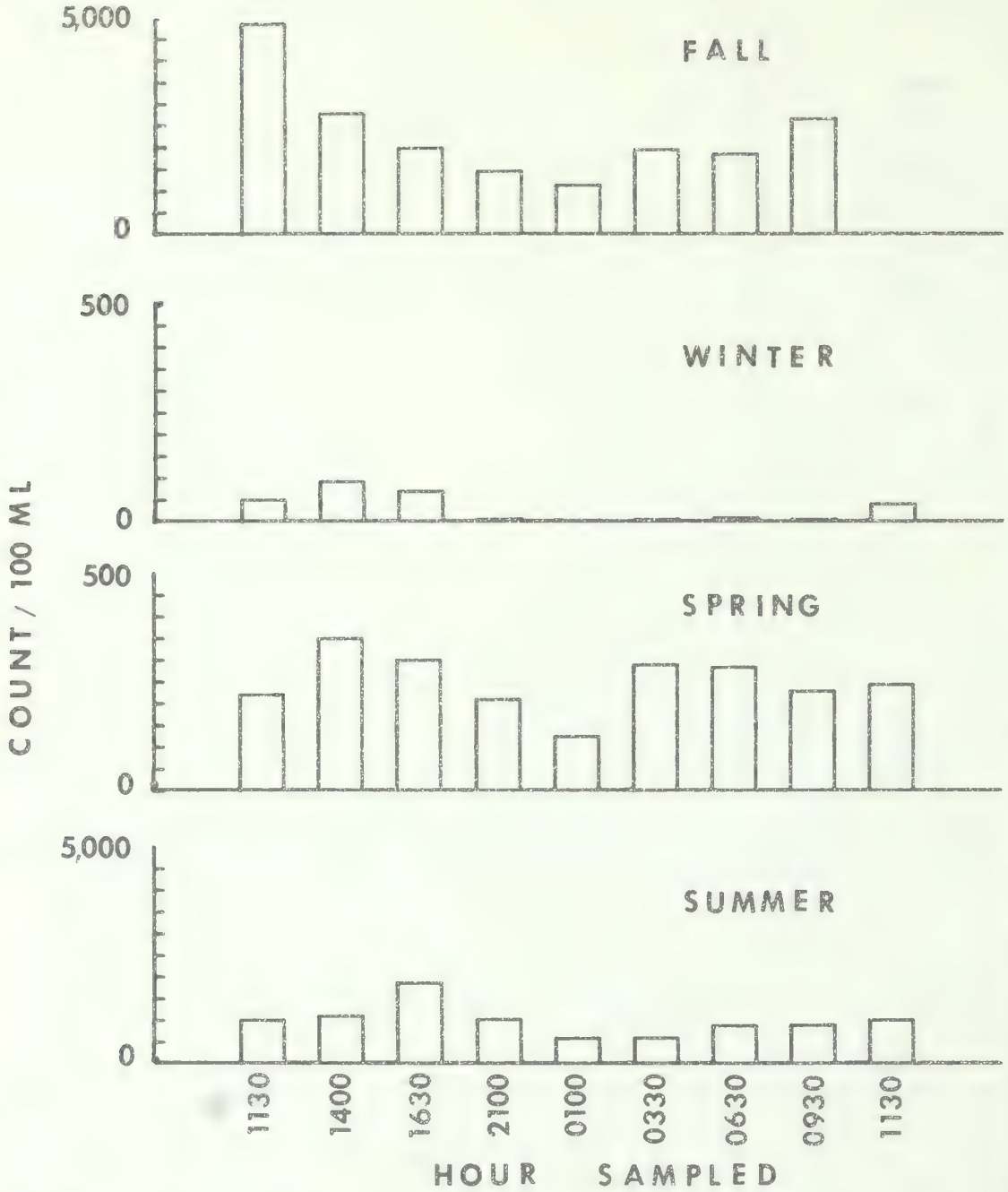

Figure 3.--Diurnal fluctuations in total coliforms at Shope Fork during nonstorm periods, according to season.

pattern (table 1). Dissolved oxygen was always at the saturation or supersaturation point in Shope Fork and was, therefore, unrelated to total coliform counts. Maximum counts roughly coincided with maximum stream temperatures. However, coliform counts began to rise shortly after midnight, while stream temperatures continued to decrease until 0600 to 0800. Stream temperatures never fluctuated more than 2.0° C during any 24-hour nonstorm period.

Table 1.--Typical fluctuations in bacterial and nutrient levels and pH in Shope Fork over 24 hours (February 22-23, 1973)

Sample time	Total coliforms	Fecal coliforms	Fecal streptococci	NO_3-N	NH_4-N	$PO_4^{\equiv}$	$C1^-$	K^+	Na^+	Ca^{++}	Mg^{++}	pH
	---- Count/100 ml ----			---------- µg/liter ----------								
1130	50	0	2	5	4	4	540	317	719	719	303	7.40
1400	90	0	0	5	2	3	520	442	789	720	343	7.35
1630	70	0	1	7	1	4	595	311	681	725	307	7.20
2100	6	1.0	0	5	1	4	520	310	717	737	326	7.00
0100	4	1.0	0	7	2	4	585	297	749	684	309	6.91
0330	6	0	0	10	2	3	515	302	713	690	302	6.91
0630	10	0	0	10	2	3	519	293	710	733	296	6.93
0930	6	0	0	7	6	3	522	300	729	729	300	6.82
1130	40	0	0	10	6	4	560	306	735	715	296	6.71

FLUCTUATIONS DURING STORMFLOW

Seven storms of varying intensity and duration were monitored at Shope Fork during this study. The winter storm shown in table 2 illustrates the response of total coliform counts to extended stormflow and elevated stream discharge. Total coliform counts generally followed the rising and falling limbs of the storm hydrograph but were not directly related to discharge rates.

Table 2.--Total coliform counts and stream measurements at Shope Fork over 24 hours during a storm (February 13-14, 1973)

Sample time	Total coliforms	Precipitation since last sample	Streamflow	pH	Water temperature
	Count/100 ml	cm	m^3/second		°C
1400	76	0	0.474	6.63	5.5
1600	26	0	.480	6.71	5.9
1900	110	.03	.480	6.85	5.9
2300	220	.48	.566	7.35	6.0
0200	74	.53	.579	6.51	6.0
0500	52	.05	.727	7.30	5.9
0800	44	1.09	.942	6.70	6.0
1100	350	1.32	1.072	6.62	7.0
1400	88	.31	.910	6.80	7.0

The fall storm shown in table 3 was intense but of short duration and illustrates the differences found in baseline recovery rates for total coliforms, fecal coliforms, and fecal streptococci. During storm periods, both fecal coliform and fecal streptococcus counts increased, but the relative proportions of the two populations changed during the course of the storm and during the stream's recovery period. Fecal streptococcus counts increased quickly after the onset of precipitation and decreased abruptly after its cessation. The fecal coliform count exhibited a more gradual increase after the onset of precipitation and remained elevated longer after its cessation. Total coliform counts peaked at 1500 hours and had recovered to near baseline levels by 0130 hours, indicating a recovery time of 10.5 hours from the cessation of precipitation. A slight count rise coincided with a small shower at 0430 hours, but total coliform counts had again recovered by the next sampling period 3.5 hours later. The peak in the FC/FS ratio lagged behind the total coliform peak by 7.5 hours. However, the FC/FS ratio apparently recovered at the same time as the total coliform count.

Table 3.--Bacterial counts and FC/FS ratios at Shope Fork during and after a storm (September 27-28, 1972)

Sample time	Total coliforms	Fecal coliforms	Fecal streptococci	FC/FS ratio	Precipitation since last sample
	- - - - Counts/100 ml - - - -				cm
Prestorm	1,460	16	62	0.26	--
0915	7,000	36	240	.15	1.32
1215	2,300	22	270	.08	.86
1500	34,900	370	1,490	.25	.56
1930	6,500	76	240	.32	0
2230	6,400	28	60	.47	0
0130	1,500	14	52	.27	0
0430	1,850	18	420	.04	(1)
0800	1,500	20	68	.29	0

[1]Trace.

CAMPGROUND STUDY

Data collected over a 3-day period near Standing Indian Campground followed the same trend as did the data from Shope Fork. Total coliform counts in Kimsey Creek at the control station above the campground fluctuated diurnally, ranging from 3,876/100 ml to 220/100 ml. Immediately below the campground, total coliform counts in Kimsey Creek ranged from 6,840/100 ml during the period of maximum recreational use to 312/100 ml during periods of minimum use. Similar trends for total coliforms were observed during a shorter sampling period at the Nantahala River, where diurnal fluctuations at the control station above the creek mouth ranged from 4,320/100 ml to 468/100 ml and those below the creek mouth ranged from 8,640/100 ml to 512/100 ml. Both control stations had daily highs at 1200 to 1500 hours and daily lows at 0600 to 0900 hours. FC/FS ratios fluctuated randomly between 0 and 1.3 at the two controls, while the ratios for the two areas below the campground increased markedly during periods of maximum recreational use (fig. 4). Peaks of 0.6 and 1.5 in the FC/FS ratios for Kimsey Creek and of 4.62 and 7.5 for the Nantahala River coincided with wading and swimming in both streams during the warmer hours of the last two sampling days and partial damming of Kimsey Creek by Boy Scouts on the third day. It should be noted that the lower sampling point on the Nantahala River was 1.2 km downstream from the river area where human activity was greatest and 2.4 km downstream of the area of greatest activity in Kimsey Creek. Other observed activities included fishing, the driving and washing of automobiles in Kimsey Creek, and the discharging of showers and dishwater from campsites adjacent to Kimsey Creek. The latter occurred

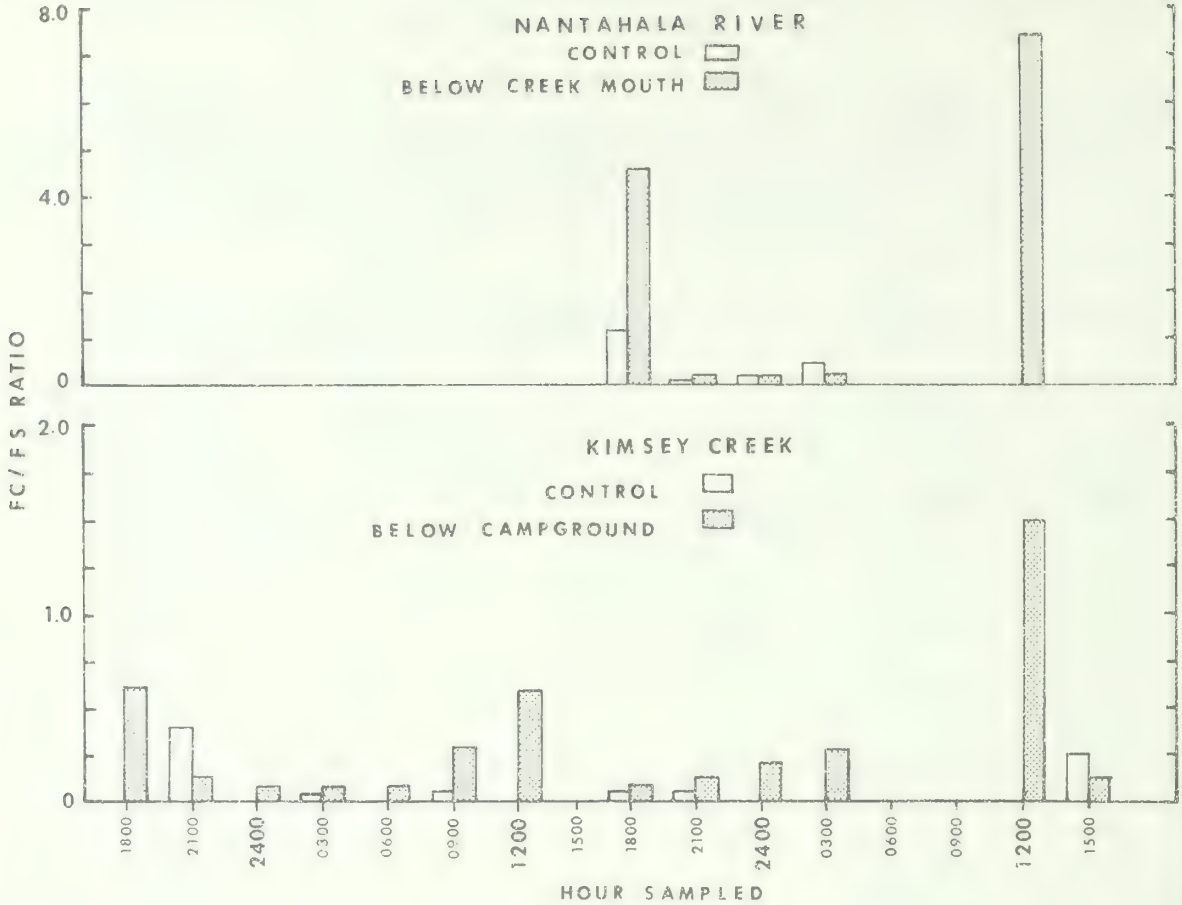

Figure 4.--Fluctuation of the FC/FS ratio in the Nantahala River and Kimsey Creek near Standing Indian Campground over a 3-day period.

primarily between 0600 and 0800 hours and, to a lesser extent, between 1800 and 2100 hours.

DISCUSSION

Despite extensive literature on enteric bacteria in surface waters, the biological processes affecting coliform bacteria in oligotrophic streams are not well understood. This study indicates that the annual fluctuation of coliform bacteria in Shope Fork is regulated by stream temperatures and that enteric bacteria multiply when stream temperatures rise. Our data support Hendricks and Morrison's (1967) findings that at low nutrient levels enteric bacteria in mountain streams increase significantly at temperatures above 16° C but that little or no growth occurs below 10° C.

Hendricks (1971) suggested that, even in oligotrophic streams, enteric bacteria might multiply in stream bottoms because of the ability of sediments to concentrate overlying dissolved nutrients. Our study lends support to this

hypothesis. Although levels of dissolved nutrients in Shope Fork were only 1/6 to 1/10 as high as those Hendricks (1971) ascribed as minimal for growth of heterotrophic bacteria, Kerr and others (1971) showed that even small additions of inorganic N, P, and C can stimulate such growth. When storms occurred at Shope Fork while water temperatures were above 10° C, the total coliform count appeared to be a function of the amount of sediment in suspension. Although no turbidity measurements were taken, the timing between increases in total coliform counts and in stream discharge were very similar to known timings between increases in turbidity and in stream discharge (Morisawa 1968). The occasionally high FC/FS ratios in the Nantahala River were probably due not to direct human input but to the stirring of bottom sediments by campers. Concurrent data on stream turbidity and bacterial counts are needed to test this hypothesis.

The sharp increases and decreases in fecal streptococcus counts noted with the onset and cessation of storms indicate that these counts were directly related to precipitation but, unlike total and fecal coliform counts, were not related to the amount of suspended sediment. During precipitation, fecal streptococci are probably transported to streams from overhanging vegetation. Our data, therefore, support the theories of Mallman and Sypien (1934) and Hanes and others (1965) that oligotrophic stream bottoms do not support substantial populations of fecal streptococci and that such enterococci may serve as a more reliable index of water pollution than do coliforms.

In the four oligotrophic streams observed in this study, bacterial counts were highest in the afternoon and lowest at night. Similar diurnal cycles have previously been reported in rivers (Coleman and others 1974) and other mountain streams (Kunkle and Meiman 1968). Lakes and ponds, however, exhibit diurnal cycles opposite from those observed in this study (Silvey and Roach 1964; Kerr and others 1971). Kerr and others (1971) reported that heterotrophic bacteria in ponds were maximum from 2400 to 0600 hours and minimum from 1400 to 1800 hours. They suggested that both biotic and abiotic factors, among them the cycling of nutrients, regulate seasonal and short-term fluctuations in aquatic populations.

The low FC/FS ratios in Shope Fork indicate that the stream is not affected by human activity, and it is unlikely that animal activity can account for the observed cycles. Nor were bacterial levels correlated with small diurnal changes in stream temperature. Perhaps, as has been suggested by Silvey and Roach (1964), the heterotrophic bacteria in the bottom sediment are responding to population changes in light-sensitive autotrophic organisms on which they rely.

A more likely explanation for the observed cycles is that the bacterial populations at Shope Fork are responding to diurnal fluctuations in streamflow. Baseflow in Coweeta streams is known to be at a minimum in late afternoon and maximum late at night (Dunford and Fletcher 1947). Any increase in streamflow that did not disturb bottom sediments would have a diluting effect on the total number of bacteria recovered per unit volume of sample. This mechanism probably accounts for the inverse relationship observed between total coliform counts and diurnal fluctuations in streamflow at Shope Fork.

LITERATURE CITED

American Public Health Association
1971. Standard methods for the examination of water and wastewater, p. 678-692. 13th ed. Am. Public Health Assoc., Inc., New York.

Coleman, R. N., J. N. Campbell, F. D. Cook, and D. W. S. Westlake
1974. Urbanization and the microbial content of the North Saskatchewan River. Appl. Microbiol. 27:93-101.

Dunford, E. G., and P. W. Fletcher
1947. Effect of removal of streambank vegetation upon water yield. Trans. Am. Geophys. Union 28(1):105-110.

Geldreich, E. E.
1966. Sanitary significance of fecal coliform in the environment. Water Pollut. Control Res. Ser. Publ. WP-20-3, 122 p. Fed. Water Pollut. Control Adm., Cincinnati Water Res. Lab.

Hanes, V. N., G. A. Delaney, and C. J. O'Leary
1965. Relationship between Escherichia coli, Type I, coliform and enterococci in water. J. Boston Soc. Eng. 52:129-140.

Hendricks, C. W.
1971. Enteric bacterial metabolism of stream sediment eluates. Can. J. Microbiol. 17:551-556.

Hendricks, C. W., and S. M. Morrison
1967. Multiplication and growth of selected enteric bacteria in clear mountain stream water. Water Res. 1:567-596.

Hewlett, J. D., and A. R. Hibbert
1965. Factors affecting the response of small watersheds to precipitation in humid areas, p. 275-290. In W. Sopper and H. Lull (eds.), International symposium on forest hydrology. Pergamon Press, New York.

Kerr, P. C., D. F. Parris, and J. T. Barrett
1971. The interrelation of carbon and phosphorus in regulating heterotrophic and autotrophic populations in an aquatic ecosystem, Shriner's Pond. Nutr. and Eutrophication 1:41-62.

Kunkle, S. H., and J. R. Meiman
1968. Sampling bacteria in a mountain stream. Colo. State Univ. Hydrol. Pap. 28, 27 p.

Mallmann, W. L., and A. Sypien
1934. Pollution indices of natural bathing places. Am. J. Public Health 24:681-688.

Morisawa, Marie
1968. Transportation of the sediment load, p. 59-64. In P. Hurley (ed.), Streams: their dynamics and morphology. McGraw-Hill Book Co., Inc., New York.

Silvey, J. K. G., and A. W. Roach
1964. Studies on microbial cycles in surface waters. J. Am. Water Works Assoc. 56(1): 60-72.

*U.S. GOVERNMENT PRINTING OFFICE: 1978-740-271/5592. Region 4.

McSwain, Michael R., and Wayne T. Swank
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Keywords: Heterotrophic, diurnal cycles, stream discharge, stream nutrient content, turbidity.

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USDA Forest Service Research Paper SE-159 March 1977

Lift-Off of Forest Firebrands

by

Hubert B. Clements

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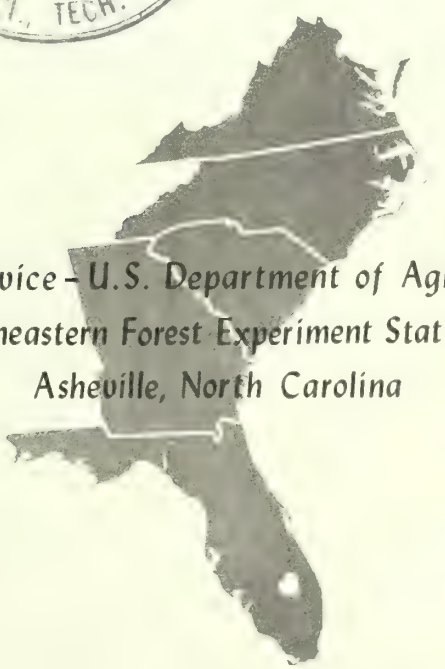

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Lift-Off of Forest Firebrands

by

Hubert B. Clements, Physicist
Southern Forest Fire Laboratory
Macon, Georgia

Abstract.--Terminal velocities of natural firebrands were determined by dropping them from given heights, timing their free fall, and integrating the equation of motion for falling objects in air. Terminal velocities are reported for leaves from 14 hardwood species, needles of 3 pine species, cones of 6 pine species, saw-palmetto fronds, Spanish moss, reindeer moss, and paper birch bark. The flaming and glowing times are also reported for cones of four pine species in flight in a vertical wind tunnel. Burning characteristics of samples of other firebrand materials were observed in flight and on landing in free-fall tests. Firebrands that had a high percentage of samples flaming in flight and on landing also tended to have higher terminal velocities. The glowing times of pine cones were found to be an order of magnitude greater than the flaming times.

Keywords: Fire research, fire management, fire behavior.

The transport of burning embers or "firebrands" to unburned areas can greatly influence the spread of a forest fire. When firebrands start spot fires across prepared lines of defense, they threaten effective control of the fire and safety of firefighters. Firebrands may distribute a few spot fires long distances ahead of the main fire front, or they may rain down near the front of a high-intensity fire and greatly increase its forward rate of spread.

Firefighters, therefore, would like to know how to predict the behavior of firebrands. Such prediction will require knowledge about terminal velocities and burnout times of important firebrands, as well as wind and fuel conditions at landing sites. Terminal velocity is needed to determine lift and flight times of a firebrand. Burnout time is needed to determine whether the firebrand is still burning at end of flight. Information gathered on materials that are likely to become firebrands is summarized here.

A firebrand is a bit of burning fuel that is transported by the updrafts that are often associated with forest fires. For a firebrand to be lifted, the updraft wind velocity must be greater than the terminal velocity of the firebrand. Terminal velocity is the maximum rate of fall that a body will achieve in still air. Terminal velocity is influenced by the size, shape, and weight of the particle.

Other factors that affect the production and transport of firebrands are the burning condition of the fuel and the prevailing wind. Cured fuel produces more firebrands than green fuel, and moderate winds appear to produce more firebrands than low or high winds. Very strong winds break up convection columns and decrease the chances of burning particles being carried aloft. Some wind, however, is required for horizontal flight.

Two other factors complicate the problem of determining firebrand behavior: changes in characteristics of burning particles and erratic flight. In general, when a burning particle is lifted by updrafts, its terminal velocity decreases as it is consumed. Irregularly shaped particles that are partly or wholly supported by updrafts tend to gyrate or spin. They may glide slowly for a while and then take on a short burst of speed.

This Paper gives the updraft velocities required to transport materials that appeared to be likely firebrands in the Southeast. It also gives the burning characteristics of a few of these materials in flight.

THEORETICAL ANALYSIS

When relative motion exists between a particle and a surrounding fluid, a drag force is exerted on the particle. This drag force (F) is given by

$$F = \frac{C_d A_p \rho_a v^2}{2 g_c} \tag{1}$$

where C_d = drag coefficient, A_p = projected area of particle in direction of motion (ft^2), ρ_a = density of fluid (lb/ft^3), v = relative velocity (ft/sec), and g_c = constant (32.17 lb-ft/lb-sec^2).

A particle falling under the action of gravity accelerates until the drag force just balances the particle's weight. The particle falls at a constant velocity known as the terminal velocity (v_t) as given by

$$v_t = \sqrt{\frac{2\ gm(\rho - \rho_a)}{\rho \rho_a A_p C_d}} \tag{2}$$

where g = acceleration due to gravity (ft/sec^2), m = mass of particle (lb), ρ = density of particle (lb/ft^3), and the other variables are as previously defined.

Drag coefficients are known for several simple shapes such as spheres, cylinders, and flat plates. However, for suspected firebrand materials, no data on drag coefficients are available. Moreover, determining coefficients for such material would be difficult.

Byram (personal communication, 1967) suggested one approach for determining the terminal velocity based on the integration of the equation of motion for a falling body subjected to a resistance varying as the square of velocity. Applying Newton's second law of motion gives:

$$mg - kv^2 = ma$$

where k = a constant of proportionality and a = acceleration. Although he did not point out its possible use for determining v_t, Lamb[1] gave an equivalent equation in a discussion of the effect of atmospheric resistance on the time of descent of a falling body. Since the acceleration, a, vanishes when the body attains its terminal velocity,

$$\frac{g\,dt}{v_t^2} = \frac{dv}{(v_t^2 - v^2)}$$

Byram's solution is a transcendental expression of the terminal velocity:

$$e^{-2gy/v_t^2} = 1 - \tanh^2 (gt/v_t) \qquad (3)$$

where the particle is dropped from a height y (ft) and the time of fall is t (sec). Both of these values are substituted into equation (3) and the equation solved for v_t. Solving the equation is rather laborious due to its transcendental nature. However, equation (3) can be written as

$$e^{gy/v_t^2} = \cosh (gt/v_t)$$

and for values of $gt/v_t \geq 3$

we have

$$\cosh (gt/v_t) \approx \tfrac{1}{2} e^{(gt/v_t)}$$

with a difference ≤ 0.24 percent.

Thus, equation (3) becomes

$$2e^{(gy/v_t^2)} = e^{(gt/v_t)}$$

[1]Lamb, Horace. 1961. Dynamics. p. 349. London: Cambridge University Press.

Taking the logarithm of both sides and rearranging gives

$$v_t^2 \ln 2 - gtv_t + gy = 0$$

with the solution

$$v_t = \frac{gt + \sqrt{g^2t^2 - 4gy\ln 2}}{2\ln 2} \qquad (4)$$

MEASURING TECHNIQUES

Dropping a sphere such as a Ping-Pong® ball allows a good test of equations (3) and (4).[2] Since the drag coefficient of a sphere is known, the terminal velocity can also be found by equation (2). Therefore, free falls of eight Ping-Pong® balls dropped 10 times each from a fire tower were timed to the nearest 0.01 second.

Another way to measure velocities of falling bodies (if they are burning) is to drop them from a tower at night and photograph them with an open-shutter, still camera with a light chopper in front of the lens. The path of the burning object looks like a dashed line on the photograph (fig. 1). The time between dashes is determined by the frequency of the chopper. The distance between dashes divided by the time is the average velocity for that increment of time.

To check this light-chopper technique, five of the eight Ping-Pong® balls were dropped in the laboratory from a catwalk 25 feet above the combustion room floor into a vertically directed searchlight beam. Each of these balls was photographed with the camera shutter open during the fall and a light chopper operating in front of the camera. The light chopper was simply a 1/8-inch-thick aluminum blade (4 inches by 24 inches) rotated about its center by a synchronous electric motor. The speed of the light chopper was measured by a stroboscope. An aluminum pole painted alternately white and black at 1-foot intervals was placed near the path of the balls so that reference distances would appear in the photograph (fig. 2). The velocities found by this technique and the terminal velocity calculated by the drag equation are in good agreement with velocities found by equation (4). Experimental data were collected by three methods described to determine the terminal velocities of Ping-Pong® balls as test "fuel." An analysis of variance showed no significant difference among the methods at the 95-percent level.

As a rough test of equations (3) and (4) for an irregularly shaped firebrand, a pine cone was dropped from a 100-foot fire tower and fell in 3.3 seconds. Both equations give a value of 42 ft/sec for the terminal velocity.

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[2]Mention of commercial products in this Paper is for identification only and does not constitute endorsement by USDA to the exclusion of other products that may be suitable.

Figure 1.--A burning pine cone dropped at night from a fire tower cab is shown as a dashed line. A light chopper in front of the camera causes the dashed-line effect.

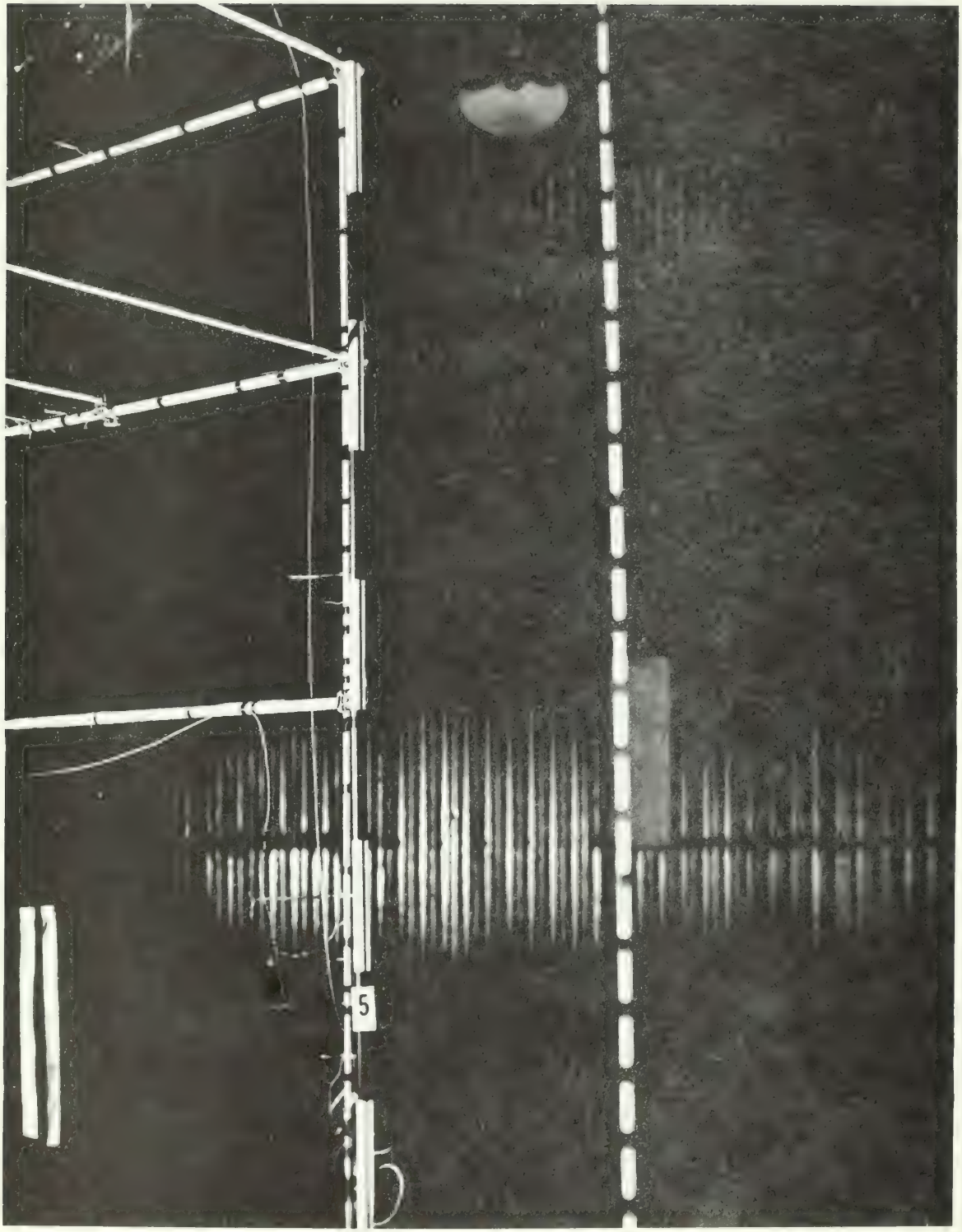

Figure 2.--A Ping-Pong ® ball falling in a searchlight beam is shown as a dashed line by placing a light chopper in front of the camera.

POTENTIAL FIREBRANDS

Terminal velocities were measured for leaves from 14 different species of broadleaf trees and for needles from 3 species of pines. Ten leaves each from 5 species of broadleaf trees were collected and tested in the spring, and 10 leaves each from 13 species were collected and tested in the fall. Each leaf was dropped three times from a catwalk 25 feet above the floor in the laboratory. The terminal velocity of each leaf was found by measuring the time of fall and applying equation (4).

Terminal velocities were also found for 10 samples each of Spanish moss and reindeer moss by dropping them from the 25-foot-high catwalk. Three drops were timed for each sample and the terminal velocities found by equation (4). Ten pine cones of each of six pine species and seven cones of another species of pine were released three times each from a 104.5-foot fire tower. Again, each drop was timed and equation (4) used to calculate the terminal velocities. Terminal velocities of 10 saw-palmetto fronds were also found by dropping them from the fire tower.

The burning characteristics of particles in flight were observed after igniting the particles and either placing them in a vertical wind tunnel or dropping them from the catwalk. The vertical wind tunnel was an inverted cone with a clear plastic shell, a horn-shaped entrance at the bottom, and a variable-speed exhaust fan at the top. The tunnel was 12.5 feet at the top. The idea of the vertical tunnel was taken from Tarifa,[3] who used such a tunnel in his studies. The flaming and glowing of 25 pine cones of four species were timed in the vertical wind tunnel. Burning characteristics of hardwood leaves, Spanish moss, reindeer moss, and samples of paper birch bark were observed in free falls from the laboratory catwalk.

As one might suspect, leaves appear to have high potential as short-range firebrands. They are often plentiful in tree crowns and are easily carried by wind. It may not be necessary for a short-range firebrand to be lifted at all. It may ignite in the crown, burn loose, and be carried beyond the fire front by horizontal winds or its natural glide path. Table 1 gives average terminal velocities for the leaves and needles of each species, as well as those of pine cones and other material.

The average terminal velocity for all broadleaves tested was 5.9 ft/sec; the range was from 2.45 ft/sec for one willow oak leaf to 10.2 ft/sec for one eastern cottonwood leaf. There seems to be no simple relationship between terminal velocities and size. For example, eastern cottonwood leaves, which are large, had an average terminal velocity of 7.04, while the small leaves of sugarberry had an average of 6.87 ft/sec. Broadleaves had lower terminal velocities in autumn than in spring.

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[3]Tarifa, C. S. 1967. Transport and combustion of firebrands. Final Reports of Grants F.G.-SP-114 and F.G.-SP-146, 90 p. USDA For. Serv., Washington, D.C., and Inst. Nac. Tex. Aerosp., Madrid, Spain.

Table 1.--Average terminal velocities

Species and season	Scientific name	Terminal velocity
		Ft/sec
Spring leaves		
Sugarberry	Celtis laevigata Willd.	6.87
American sycamore	Platanus occidentalis L.	6.59
Blackjack oak	Quercus marilandica Muenchh.	6.12
Eastern cottonwood	Populus deltoides Bartr.	5.86
Mockernut hickory	Carya tomentosa Nutt.	5.77
Fall leaves		
Sweetgum	Liquidambar styraciflua L.	7.35
Eastern cottonwood	Populus deltoides Bartr.	7.04
Mockernut hickory	Carya tomentosa Nutt.	6.72
Black willow	Salix nigra Marsh.	5.88
Southern red oak	Quercus falcata Michx.	5.88
Yellow-poplar	Liriodendron tulipifera L.	5.61
Southern magnolia	Magnolia grandiflora L.	5.52
American sycamore	Plantanus occidentalis L.	5.30
Water oak	Quercus nigra L.	5.12
Willow oak	Quercus phellos L.	5.03
Black cherry	Prunus serotina Ehrh.	4.78
Florida maple	Acer barbatum Michx.	4.39
Blackjack oak	Quercus marilandica Muenchh.	4.25
Pine needles		
Loblolly pine	Pinus taeda L.	13.54
Slash pine	Pinus elliottii Engelm.	13.09
Shortleaf pine	Pinus echinata Mill.	9.49
Cones		
Sand pine	Pinus clausa (Chapm.) Vasey	54.29
Slash pine	Pinus elliottii Engelm.	44.04
Longleaf pine	Pinus palustris Mill.	41.35
Jack pine	Pinus banksiana Lamb	35.38
Loblolly pine	Pinus taeda L.	35.16
Shortleaf pine	Pinus echinata Mill.	28.36
Other		
Paper birch bark	Betula papyrifera Marsh.	18.35
Saw-palmetto fronds	Serenoa repens (Bartr.) Small	15.15
Spanish moss	Tillandsia usneoides L.	14.92
Reindeer moss	Cladonia rangiferina (L.)	11.48

The average terminal velocity for pine needles was 12.0 ft/sec; the range was from 6.3 ft/sec for one drop of shortleaf pine to 18.3 ft/sec for one drop of slash pine. The average terminal velocity of pine needles was about twice that of hardwood leaves.

The average terminal velocity was 15.2 ft/sec for saw-palmetto fronds, 14.9 ft/sec for Spanish moss, 11.5 ft/sec for reindeer moss, and 18.4 ft/sec for paper birch bark. A wide range (10.4 to 22.4 ft/sec) found for Spanish moss may have been caused by deformation of samples during flight and between flights.

The average terminal velocities of pine cones ranged from 28.3 ft/sec for shortleaf pine to 54.3 ft/sec for sand pine. Terminal velocities were also found for 32 burning loblolly pine cones by the light-chopping technique. The average terminal velocity for these cones was 28.3 ft/sec, while the average value for the nonburning cones was 35.1 ft/sec. The 22-percent difference in average velocity is due in part to the loss in mass of the cones by burning.

Burning characteristics of pine cones in flight were observed in a vertical wind tunnel. In most cases the cones rotated and gyrated. The vertical movement usually did not exceed ± 3 feet of the main vertical position. The horizontal movement usually caused the cones to have many collisions with the wall of the tunnel. Several cones remained against the tunnel wall once they came in contact with it. The flaming and glowing times are given for four species of pine cones in table 2.

Table 2.--The average flaming and glowing times of 25 samples of 4 species of pine cones in flight

Pine species	Flaming time		Glowing time	
	Average	Maximum	Average	Maximum
	Minutes			
Loblolly	0.36	0.83	4.09	6.83
Slash	.32	.56	6.13	10.42
Longleaf	.44	1.20	7.50	13.49
Shortleaf	.15	.53	2.95	4.60

The vertical tunnel was found unsuitable for observing the burning characteristics of the other firebrands selected for study. Almost all leaf and moss samples clung to the tunnel wall, and saw-palmetto fronds and samples of paper birch bark were too large for the tunnel. The burning characteristics of hardwood leaves, needles, Spanish moss, reindeer moss, and samples of paper birch bark were observed in free fall from the catwalk. Samples of the above firebrand materials were dropped while burning. The burning condition of each sample observed in flight and upon landing is given in table 3. The larger leaves and compound leaves had a greater tendency to remain flaming in flight. Out of 100 leaves of each species, 63 American sycamore and 62 yellow-poplar leaves were flaming in flight and 40 and 51 leaves were flaming after landing. Out of 100 mockernut hickory leaves dropped, 82 leaves flamed in flight and 57 flamed on landing.

Table 3.--Burning characteristics of firebrand materials in free-fall tests

Species	Total sampled	In flight		On ground	
		Flaming	Glowing	Flaming	Glowing
		Number			
Blackjack oak	100	21	79	6	44
Southern red oak	100	56	44	29	71
Willow oak	100	1	99	0	99
Water oak	100	0	100	0	98
Sweetgum	100	14	86	7	92
Black cherry	100	4	96	2	98
Florida maple	100	4	84	1	21
Black willow	100	0	96	0	87
Yellow-poplar	100	62	38	51	45
Southern magnolia	100	43	57	34	65
American sycamore	100	63	37	40	57
Mockernut hickory	100	82	18	57	43
Winged elm[1]	100	0	79	0	59
Slash pine	50	0	49	0	36
Paper birch bark	40	40	0	39	1
Spanish moss	30	30	0	28	2
Reindeer moss	100	94	6	85	8
Pine branch tips--dead	50	32	18	16	33
Pine branch tips--green	50	17	32	7	43

[1] Ulmus alata Michx.

Of the firebrands observed in the 25-foot drop tests, those that had large percentages of samples flaming in flight and on landing also had high terminal velocities (tables 1 and 3).

CONCLUSIONS AND RECOMMENDATIONS

Terminal velocities found by the methods described approximate the updrafts required for transporting firebrands. To be a serious hazard, a material must be present in quantity and situated so that it may be lifted by updrafts. It must also be capable of igniting fuel on landing. I observed the burning characteristics of suspected materials in flight and on landing. In future tests, I recommend that potential firebrands first be allowed to land on prepared beds of dry, fine fuel to see if they start any spot fires. After the most dangerous firebrands are identified, the terminal velocities and burnout times can be determined precisely. The behavior of firebrands can be predicted from terminal velocities and burnout times plus other information. In the present study, the methods for determining terminal velocity and burnout time (flaming time plus glowing time in flight and on the ground) proved sufficiently accurate for future use in model development. These methods are also recommended for use with all important firebrands once the actual model has been developed.

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Clements, Hubert B.
1977. Lift-off of forest firebrands. USDA For. Serv. Res. Pap. SE-159, 11 p. Southeast. For. Exp. Stn., Asheville, N.C.

Terminal velocities are reported for leaves from 14 hardwood species, needles of 3 pine species, cones of 6 pine species, saw-palmetto fronds, Spanish moss, reindeer moss, and paper birch bark. The flaming and glowing times are also reported for cones of four pine species in flight in a vertical wind tunnel.

Keywords: Fire research, fire management, fire behavior.

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.11.5E-160

SDA Forest Service Research Paper SE-160 January 1977

Fusiform Rust in Loblolly and Slash Pine Plantations on High-Hazard Sites in Georgia

by

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U.S. Department of Agriculture - Forest Service

Cover photo. --Fusiform rust infections on slash pine stems may kill the trees or make them susceptible to wind breakage before they are merchantable.

Fusiform Rust in Loblolly and Slash Pine Plantations on High-Hazard Sites in Georgia

by

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Macon, Georgia

Abstract.--In two progeny test plantations of loblolly and two of slash pine, 30 percent of all the loblolly and 34 percent of all the slash seedlings planted were infected by fusiform rust by age 3. By age 15, only 10 percent of the loblolly and 13 percent of the slash pines planted were free of rust. Among trees with stem cankers at age 3, 71 percent of the loblolly and 86 percent of the slash pines died by age 15; among those free of rust at age 3, 7 percent of the loblolly and 23 percent of the slash pines died by age 15. Total volume losses to rust through age 15 in the form of mortality, reduced stem growth, and canker tissue were 42 percent for loblolly and 55 percent for slash. The test progenies varied significantly in their response to rust. Breeding for rust resistance in these two species is imperative.

Keywords: Pinus taeda, P. elliottii var. elliottii, Cronartium fusiforme, economic impact, genetic variation.

Southern fusiform rust (Cronartium fusiforme Hedgc. & Hunt ex Cumm.) is having an increasing economic impact on loblolly (Pinus taeda L.) and slash pine (P. elliottii var. elliottii Engelm.). In 1952 throughout the South, the disease caused an estimated loss in growing stock of 97 million ft^3 (2.7 million m^3), mostly in slash and loblolly pines (Hepting and Jemison 1958). By 1970 in South Carolina, Georgia, and Florida alone, rust losses from reduced cut on harvested acreages of these species were estimated at 73 to 126 million ft^3 or 2.1 to 3.6 million m^3 (Powers and others 1975).

Fusiform rust is especially severe in plantations of these two pine species. Levels of infection in such plantations are high over much of South Carolina, Georgia, Alabama, and Mississippi (Phelps 1974), having increased dramatically in this area over the past few decades (Czabator 1971; Schmidt and others 1974). Losses in infected plantations result from reduced growth of infected stems, mortality, and shortened rotations with reduced growing stock (Bailey and Malac 1974; Jones 1972; Powers and others 1974).

Little has been reported on infected patterns as the disease runs its course in planted stands. To help fill that gap, detailed studies of rust infection are reported for progeny test plantations of slash and loblolly pine on high-hazard sites in central Georgia. Genetic differences in response to rust among the progenies involved are evaluated to assess the practicability of breeding resistant strains, and volume losses as a result of rust are estimated on an area and percentage basis.

MATERIALS AND METHODS

Two plantations of loblolly (Nos. 30 and 59) and two of slash pine (Nos. 38 and 57) were studied in Bleckley County near the center of Georgia in the Upper Coastal Plain (table 1). All the plantations had 25-tree plots at 3.05- by 3.05-m spacing in randomized blocks. All seedlots except the commercial checks were wind-pollinated progenies from individual trees. Progenies in loblolly plantation 30 were from 11 trees randomly selected from each of three stands in Coweta, Glynn, and Laurens Counties, Georgia. Progenies in the other three plantations were from trees selected for good growth and form and apparent freedom from infection by fusiform rust.

Table 1.--Description of the study plantations in central Georgia

Plantation No.	Species	Year planted	Site index at age 25[1]	Progenies	Checklots
			m	- - - No. - - -	
30	Loblolly	1956	18.3	33	0
38	Slash	1956	19.8	27	2
57	Slash	1961	19.8	19	1
59	Loblolly	1961	19.8	17	3

[1]Values for loblolly pine were estimated from Clutter and Lenhart (1968) and those for slash pine from Bennett and others (1959).

Tallies of rust infection and mortality were made for each tree at ages 3 and 15 years in plantations 30 and 38 and at ages 3, 5, 10, and 15 years in plantations 57 and 59. The cause of mortality occurring before age 3 was not determined. Heights and d.b.h. were measured at age 15 and used to estimate the volume of each tree by formula for slash pine (Schmitt and Bower 1970) and from tables for loblolly pine (Bailey and Clutter 1970). Infection data for each tree were used to determine the effect of rust on its survival and growth. Survival, mortality, infection, and growth data were used to study the response of the progenies to fusiform rust and to estimate wood losses caused by the rust.

RESULTS AND DISCUSSION

PLANTATION AVERAGES

The slash and loblolly plantations (Nos. 30 and 38) established in 1956 had higher early mortality and were more heavily infected by fusiform rust at age 3 than were those (Nos. 57 and 59) planted in 1961 (fig. 1). By age 5, however, the latter two plantations had also become heavily infected. This delay in infection resulted in less mortality between ages 3 and 15 in plantations 57 and 59 than in plantations 30 and 38--10 percentage points less for loblolly and 2 percentage points less for slash.

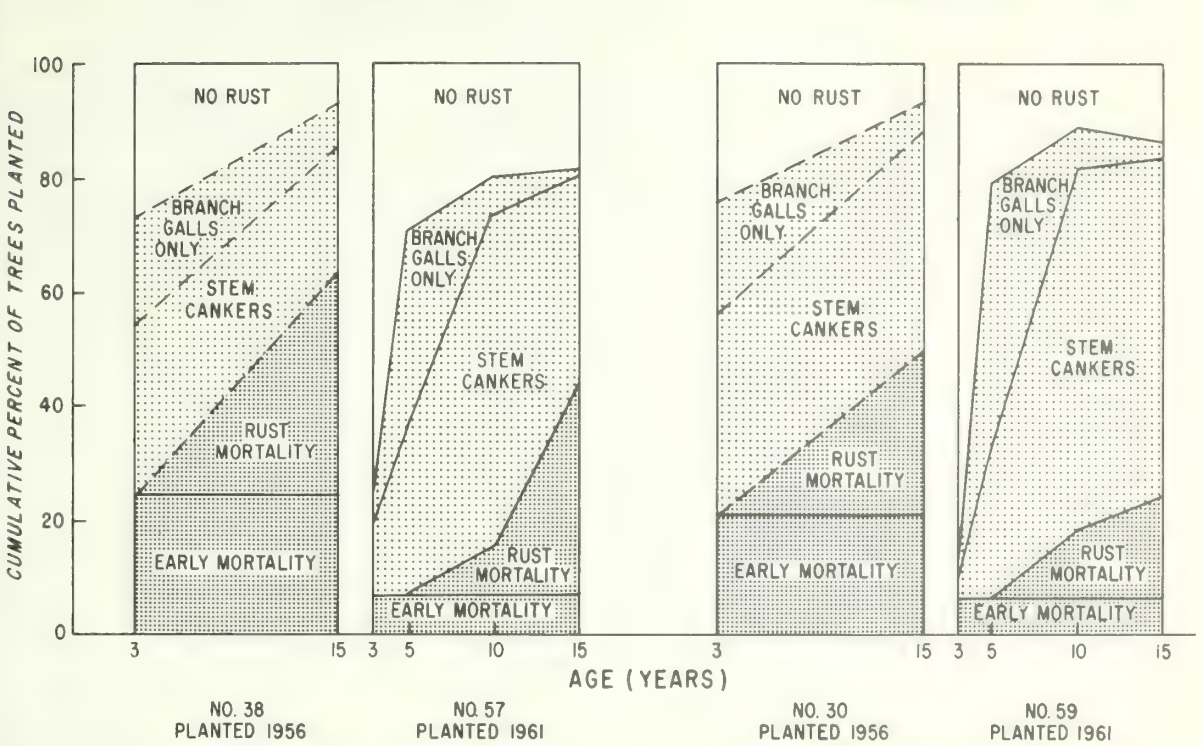

Figure 1.--Average mortality and rust infection status at different ages for all trees in the two slash and two loblolly pine plantations.

Average rates of early mortality and early infection were similar for the two species. Rust-caused mortality between ages 3 and 15, however, was 15 percentage points higher for slash than for loblolly pine. Because of this difference plus the slightly higher early mortality of the slash pine, survival at age 15 was 17 percentage points lower for slash than for loblolly (46 percent vs. 63 percent).

When living trees at age 3 were classified as stem-cankered, branch-galled only, or rust-free, the slash pines in all three categories were shown to be more readily killed by rust by age 15 than were the loblolly pines, with the highest mortality among stem-cankered trees (table 2). Bailey and Malac (1974) also found slash pine to be more likely than loblolly pine to die from stem infections. In this study, trees of either species with stem cankers by age 3 had a high probability of dying by age 15.

At age 15, trees with stem cankers had less volume than those with rust-free stems (table 3). Mean differences in volume per tree between cankered and clean stems were highly significant (0.01 level) for all four plantations. The average decrease in volume of cankered stems was 17 percent for loblolly and 18 percent for slash.

Table 2.--Mortality between ages 3 and 15 for trees in three rust infection categories at age 3, by plantation and species

Infection category at age 3	Plantation average				Species average	
	Slash		Loblolly		Slash	Loblolly
	38	57	30	59		
	Percent mortality					
Stem-cankered	89.6	82.2	64.5	76.8	85.9	70.6
Branch-galled only	42.4	50.8	7.6	33.3	46.6	20.4
Rust-free	18.4	28.1	3.0	11.7	23.2	7.3

Table 3.--Average volumes of individual trees with clean and cankered stems at age 15, by species and plantation

Species and plantation		Trees		Average volume per tree		Decrease in volume per tree, cankered vs. clean
		Stems clean	Stems cankered	Stems clean	Stems cankered	
		No.		m^3		Percent
Slash	38	326	479	0.249	0.201	19
	57	608	1080	.171	.142	17
Loblolly	30	395	1227	.204	.159	22
	59	325	1179	.160	.141	12

PROGENY VARIATION

The different progenies varied widely in their response to fusiform rust (table 4). They varied in their susceptibility both to infection and to being killed by the rust once stems had been cankered, no matter whether infection occurred by age 3 or at some later age. The loblolly progenies in plantation 30 had significant variation in fewer of the response variables than did progenies in the other plantations, partly because of greater plot-to-plot variation within progenies in plantation 30.

Table 4.--Variation among progenies in levels of infection and mortality caused by fusiform rust in the four plantations

Variable[1]	Slash plantation		Loblolly plantation	
	38	57	30	59
	Coefficient of variation (percent)[2]			
Alive at 3, infected at some time	**12.1	**11.0	**11.2	** 9.4
Rust-free at 3, infected by 15	**29.8	**12.9	29.2	** 9.7
Stem-cankered at 3, died by 15	*23.7	*28.4[3]	**26.3	* 51.4[3]
Branch-galled only at 3, died by 15	64.3	**36.5[3]	103.5	92.3[3]
Rust-free at 3, died by 15	*75.2	*23.6	140.5	**42.3

[1] All variables were the arcsin square-root transformation of percentages.
[2] The coefficients are a measure of relative variation among plot averages within progenies.
** indicates significant variation among progenies at the 1-percent level by F-tests; * indicates significant variation among progenies at the 5-percent level by the same tests.
[3] Fifth-year rather than third-year data, because infection levels at age 3 were low.

In the three plantations which included checklots (Nos. 38, 57, and 59), progenies from selected trees generally averaged better than the checks in their response to rust. However, Dunnett's (1955) procedure for testing treatments against controls showed that only a few progenies were significantly better than the checks. There generally was greater variation among the slash progenies than among the loblolly progenies, indicating that selection for rust resistance may yield faster gains in slash than in loblolly pine. There was also more variation among progenies in plantations that had been heavily infected by age 3 than among progenies in plantations that had not been heavily infected until age 5.

Those progenies with the highest incidences of rust infection (branch or stem galls) at an early age were also the ones whose trees infected with early stem galls tended to be most readily killed. Among the progenies in three plantations, there was significant correlation between the percentage of trees with early infection and the percentage that died by age 15 from early stem cankers (table 5). This correlation indicates that the mechanism which renders a tree susceptible to infection is either the same as or is genetically linked to the mechanism which causes or permits cankers to grow rapidly and kill the tree.

The level of rust infection in the different progenies at age 3 or 5 was negatively correlated with survival and volume per hectare at age 15 (table 6). All correlations were significant except those for loblolly plantation 59. The average infection level was quite low at age 3 in this plantation, and although high levels of infection had occurred by age 5, survival to age 15 in the plantation has been high (fig. 1). Consequently, differences in early infection levels among the loblolly progenies in plantation 59 have not yet strongly influenced differences in survival and volume per hectare.

Table 5. --Correlation between percentage of living trees infected with fusiform rust at age 3 or 5 within a progeny and the percentage that died by age 15 from stem cankers present at the same early age

Correlation	Third-year data		Fifth-year data[1]	
	Plantation		Plantation	
	38 (Slash)	30 (Loblolly)	57 (Slash)	59 (Loblolly)
Coefficent	0.47	0.63	0.53	0.30
Significance level	.01	.01	.05	.10

[1]Infection levels in plantations 57 and 59 were too low at age 3 for meaningful analysis of this correlation.

Table 6. --Relationship between percentages of fusiform rust infection in living trees of the various progenies at age 3 or 5 (x) and survival and volume per hectare at age 15 (y)

Coefficient or value	Survival				Volume			
	Slash plantation		Loblolly plantation		Slash plantation		Loblolly plantation	
	38[1]	57[2]	30[1]	59[2]	38[1]	57[2]	30[1]	59[2]
Correlation (r)	-0.65	-0.75	-0.74	-0.38	-0.61	-0.85	-0.54	-0.10
	Percent				m^3/ha			
Regression (b)	-0.55	-0.62	-0.79	-0.25	-1.10	-1.44	-1.17	-0.15
S.E. of b (±)	.12	.13	.13	.32	.28	.29	.33	.74
Y-intercept (a)	72	98	105	104	151.0	186.5	170.4	141.9

[1] Infection at age 3.
[2] Infection at age 5.

The large differences among the various progenies in susceptibility to fusiform rust indicate that genetically resistant strains could be developed. Other analyses of the data from slash pine plantation 38 have shown that rust incidence at age 15 in the second generation could be decreased by 40 to 50 percent, in comparison with commercial checks, by selection and progeny testing followed by selecting the best families (Sluder 1975). But would the expense of breeding for rust resistance be justifiable in terms of increased volume production? Estimates of all volume losses associated with rust infection are necessary before that question can be answered.

VOLUME LOSSES

Fusiform rust infections can cause volume losses through mortality, reduced growth of infected stems, and reduced utility of stem canker tissue. Canker tissue has no value for solid wood products and reduced value as pulpwood.[1] We have already seen that rust in these plantations has caused mortality and that stem infections have reduced average stem volume, but these effects can be more easily compared if estimated as volume losses per hectare or percentages of expected volume lost.

The Y-intercept values in table 6 represent the volumes per hectare expected at age 15 in the absence of growth losses to fusiform rust through mortality and reduced growth in infected stems. Growth losses for each plantation were determined by subtracting actual volumes per hectare measured at age 15 from the expected volumes. In plantation 38, for example, the expected volume was 151.0 m^3/ha, the measured volume was 80.1 m^3/ha, and the difference or growth loss was 70.9 m^3/ha. In order to separate this growth loss into its two components, data from table 3 were used to calculate the volume loss per hectare in reduced stem growth. That value was subtracted from the total growth loss to get the volume lost to mortality. For plantation 38, the loss in reduced stem growth was 11.3 m^3/ha and mortality loss was 59.6 m^3/ha (table 7).

Table 7.--Estimated losses caused by fusiform rust in the four plantations to age 15; expressed as volume per hectare, inside bark, total tree

Volume	Slash plantation		Loblolly plantation	
	38	57	30	59
	m^3/ha			
Volume expected in absence of rust	151.0	186.5	170.4	141.9
Measured volume	80.1	87.9	88.9	114.1
Growth loss	70.9	98.6	81.5	27.8
Mortality	59.6	87.2	63.6	15.8
Reduced stem growth	11.3	11.4	17.9	12.0
Stem canker tissue	7.6	9.0	10.8	14.2
Total loss to rust	78.5	107.6	92.3	42.0

[1]Veal, M. A., R. L. Blair, J. B. Jett, and W. T. McKean. 1975. Impact of fusiform rust on pulping properties of young loblolly and slash pine (abstr.). Southwide For. Dis. Workshop Proc., Feb. 1975, Gulfport, Miss. [Limited distribution.]

Canker tissue in stems of trees living at age 15 represents additional losses. These losses were determined by using the value of 16 percent found by Veal[2] to be the average proportion of stem volume occupied by cankers in infected stems of loblolly pine at age 10. I assume the same percentage applies to slash pine and holds to age 15 for both species. This value was multiplied by the percentage of infected stems in each plantation to get the percentage of total stem volume occupied by canker tissue. For plantation 38, the calculations were 59.5 percent x 16 percent = 9.5 percent of the measured volume at age 15, or 7.6 m^3/ha. Thus, the total loss to fusiform rust to age 15 in plantation 38 was 78.5 m^3/ha (table 7) or 51.9 percent of the volume expected in the absence of rust (table 8). Total losses were even greater in plantations 30 and 57.

Table 8.--Losses caused by fusiform rust in the four plantations to age 15; expressed as percentages of volumes expected in absence of rust

Loss	Slash		Loblolly	
	Plantation 38	Plantation 57	Plantation 30	Plantation 59
	Percent			
Growth loss	46.9	52.9	47.8	19.6
Mortality	39.5	47.0	37.3	11.1
Reduced stem growth	7.4	5.9	10.5	8.5
Stem canker tissue	5.0	4.8	6.3	10.0
Total loss to rust	51.9	57.7	54.1	29.6
Species average	54.8		41.8	

CONCLUSIONS

Although these four plantations constitute a very small sample, the volume and percentage losses shown in tables 7 and 8 clearly demonstrate both the need for and potential gain from breeding for rust resistance in slash and loblolly pines. Several generations of breeding may be required to achieve the full potential, but substantial gains can be made in one generation by selection and progeny testing (Sluder 1975).

The magnitude of the losses reported indicates that economic gains from the use of planting stock genetically resistant to fusiform rust would justify any foreseeable costs involved in its development (Davis 1967). If these losses approximate those in the vast area in the Southeast subject to high levels of fusiform rust inoculum, the question is not whether breeding rust-resistant slash and loblolly pines can be economically justified, but whether plantation forestry with these two species can be justified without it.

[2]Veal, M. A. 1973. Fusiform rust impact. Unpubl. internal rep., Coop. Programs & Dep. Wood and Pap. Sci., N. C. State Univ., Raleigh, N. C. 9 p.

Errata: This page should be inserted at the end of Research Paper SE-160, "Fusiform Rust in Loblolly and Slash Pine Plantations on High-Hazard Sites in Georgia," by Earl R. Sluder.

LITERATURE CITED

Bailey, Harry B., Jr., and Barry F. Malac
1974. Mortality in rust-infected southern pine plantations. Union Camp Corp. Woodlands Res. Notes 31, 4 p.

Bailey, Robert L., and Jerome L. Clutter
1970. Volume tables for old-field loblolly pine plantations in the Georgia piedmont. Ga. For. Res. Counc. Rep. 22--Ser. 2, 4 p.

Bennett, F. A., C. E. McGee, and J. L. Clutter
1959. Yield of old-field slash pine plantations. USDA For. Serv. Southeast. For. Exp. Stn. Pap. 107, 19 p. Asheville, N. C.

Clutter, Jerome L., and J. David Lenhart
1968. Site index curves for old-field loblolly pine plantations in the Georgia piedmont. Ga. For. Res. Counc. Rep. 22--Ser. 1, 7 p.

Czabator, Felix J.
1971. Fusiform rust of southern pines--a critical review. USDA For. Serv. Res. Pap. SO-65, 39 p. New Orleans, La.

Davis, Lawrence S.
1967. Investments in loblolly pine clonal seed orchards. J. For. 65:882-887.

Dunnett, C. W.
1955. A multiple comparisons procedure for comparing several treatments with a control. J. Am. Stat. Assoc. 50:1096-1121.

Hepting, George H., and George M. Jemison
1958. Forest protection, p. 184-220. In Timber resources for America's future. USDA For. Serv. For. Resour. Rep. 14. Washington, D. C.

Jones, Earle P., Jr.
1972. Fusiform rust affects planted slash pine. J. For. 70:350-352.

Phelps, William R.
1974. Evaluation of fusiform rust incidence on loblolly and slash pine in the South. U.S. Dep. Agric. Plant Dis. Rep. 58:1137-1141.

Powers, H. R., Jr., J. P. McClure, H. A. Knight, and G. F. Dutrow
1975. Fusiform rust: Forest survey incidence data and financial impact in the South. USDA For. Serv. Res. Pap. SE-127, 16 p. Southeast. For. Exp. Stn., Asheville, N. C.

Powers, H. R., Jr., F. R. Matthews, and R. B. Hawes
1974. Volume loss resulting from fusiform rust in young plantations of slash pine. USDA For. Serv. Res. Note SE-200, 8 p. Southeast. For. Exp. Stn., Asheville, N. C.

Schmidt, R. A., R. E. Goddard, and C. A. Hollis
1974. Incidence and distribution of fusiform rust in slash pine plantations in Florida and Georgia. Univ. Fla. Agric. Exp. Stn. Tech. Bull. 763, 21 p.

Schmitt, Dan, and Dave Bower
1970. Volume tables for young loblolly, slash, and longleaf pines in plantations in south Mississippi. USDA For. Serv. Res. Note SO-102, 2 p. + tables. South. For. Exp. Stn., New Orleans, La.

Sluder, Earl R.
1975. Fifteenth-year results from progeny tests of slash pine. USDA For. Serv. Res. Pap. SE-140, 15 p. Southeast. For. Exp. Stn., Asheville, N. C.

Correct citation for library cards should read:

Sluder, Earl R. 1977. Fusiform rust in loblolly and slash pine plantations on high-hazard sites in Georgia. USDA For. Serv. Res. Pap. SE-160, 10 p. Southeast. For. Exp. Stn., Asheville, N. C.

Sluder, Earl R.

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In two progeny test plantations of each species on high-hazard sites in Georgia, only 10 percent of the loblolly and 13 percent of the slash pines planted were free of rust by age 15. Total volume losses to rust through age 15 in the form of mortality, reduced stem growth, and canker tissue were 42 percent for loblolly and 55 percent for slash pine.

Keywords: Pinus taeda, P. elliottii var. elliottii, Cronartium fusiforme, economic impact, genetic variation.

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USDA Forest Service Research Paper SE-161 April 1977

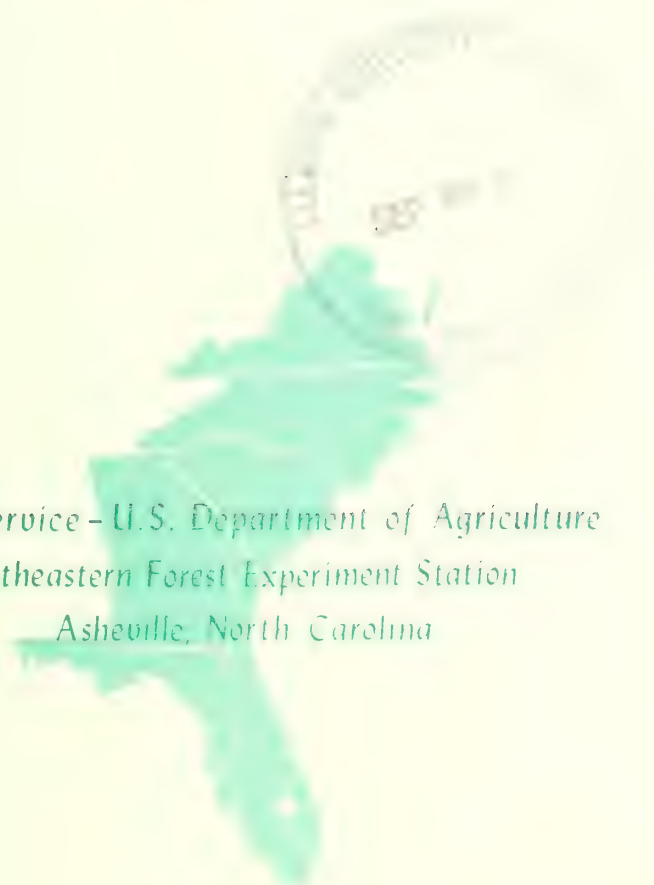
Competition-Density Effects in a Loblolly Pine Seedling Stand

by

William R. Harms

and

O. Gordon Langdon



Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Competition-Density Effects in a Loblolly Pine Seedling Stand

by

William R. Harms, Principal Plant Physiologist

and

O. Gordon Langdon, Principal Silviculturist
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Abstract.--As seedling stand density increased, average plant dry weight, leaf weight, leaf surface area, and length and thickness of needles decreased. Leaf weight by itself accounted for more variation in plant dry weight than either stand density or the other leaf variables. The major effect of density on seedling development was attributed to competition for light.

Keywords: Leaf area, leaf thickness, dry weight, light.

To fully exploit the potentials of trees for fiber production, we need a better understanding of how competition for growing space affects the biological systems responsible for growth--the roots and crowns. This area of research has been neglected because of the great difficulty in obtaining data from large trees. A partial solution is to study competition in seedling stands.

The study described here was designed to examine the effects of competition on the first-year growth of loblolly pine (Pinus taeda L.) seedlings. We were especially interested in how weight, surface area, length, and thickness of the needles were influenced by stand density. In agricultural crops, these attributes of crown structure are known to be related to the rate and amount of dry matter production (Evans 1972; Watson 1952). Undoubtedly, they are also important in forest growth but have been little studied in trees (Jarvis and Jarvis 1964; Ledig and Perry 1969; Wareing 1964).

METHODS

Space and seedlings for the study were provided by Westvaco Corporation in their nursery near Summerville, South Carolina. Nursery personnel prepared a nursery bed, sowed the seeds, and cared for the seedlings in the standard ways.

Loblolly seeds were sown in drills 15 cm apart in mid-April. In early July, plots 30 cm square were located and thinned to provide five replications for a randomized complete block design. Twelve seedling density classes ranging from 100 to 700 seedlings per square meter were established. A 15-cm border strip around each plot was also thinned to the density of the plot itself. The seedlings were harvested the following February, 10 months after sowing. In the laboratory, fresh weight of each seedling was measured to the nearest 0.1 g, and the seedlings from each plot were divided into 5-g weight classes. A sample of 10 percent of the seedlings was taken from each weight class for measurement of length and number of needle fascicles. The volume of fascicles on these seedlings was determined to the nearest 0.01 cm^3 by displacement in water. All seedlings on the plot were then ovendried to constant weight at 72° C, and the average seedling dry weight was calculated.

Leaf area of the sample trees was estimated with Kozlowski and Schumacher's (1943) equation which expresses surface area in terms of needle fascicle volume. Plot leaf area was computed by expanding the leaf area of the sample seedlings in proportion to the number of seedlings in each of the weight classes in a given plot. Average leaf area of the crowns of that plot was then obtained by dividing the estimate of plot leaf area by the number of seedlings. A weighted average of needle length was calculated in a similar manner. An index of leaf thickness was obtained by dividing total needle weight of the sample seedlings by total needle length and expanding to the plot basis. The results were expressed as needle weight per unit of needle length (g/cm).

Relationships between bed density and various expressions of seedling growth were examined by regression analysis.

RESULTS

Seedling dry weight was significantly related to bed density (figs. 1 and 2). There was an initial sharp decrease followed by a more gradual reduction in weight as density increased further. The curves fitted to the data are of the form $\log_{10} Y = a + b \log_{10} X$, where Y is the dry weight of the seedling part, and X is density in numbers of seedlings.

Regression equations for the curves in figures 1 and 2 and for total seedling weight are:

Log leaf weight = 1.6632 - 0.6295 log density; $r^2 = 0.83$

Log stem weight = 1.3153 - 0.4822 log density; $r^2 = 0.76$

Log root weight = 1.6519 - 0.6822 log density; $r^2 = 0.75$

Log seedling weight = 2.0058 - 0.5889 log density; $r^2 = 0.83$

All regressions are significant at the 1-percent level. The curve for leaf plus stem weight in figure 1 was obtained by adding the leaf and stem curves from figure 2.

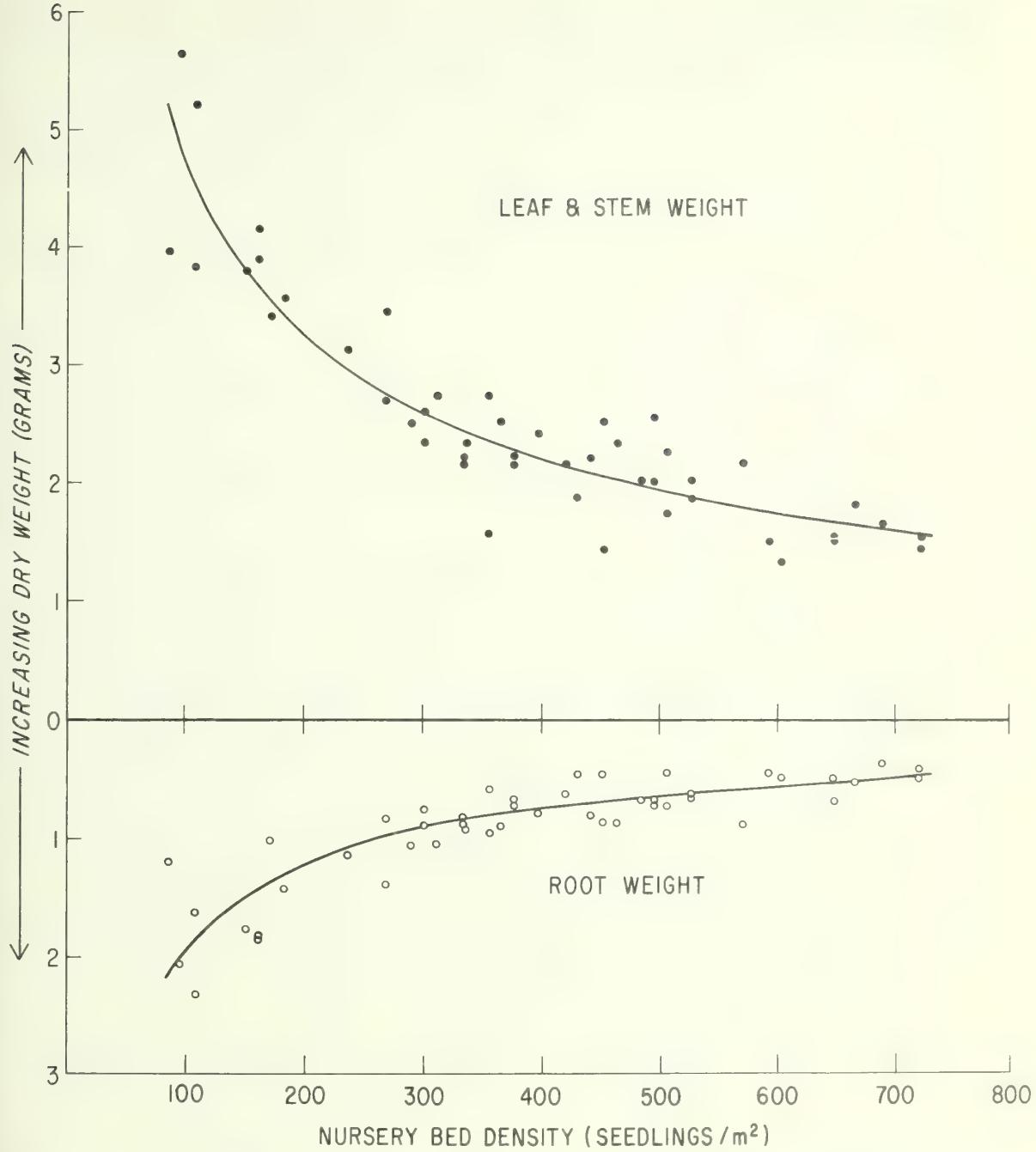

Figure 1.--Effect of nursery bed density upon root weight and leaf plus stem weight of loblolly pine seedlings.

Since the zero ordinate of figure 1 represents the surface of the soil, the data as plotted also indicate the effect of density on the partitioning of dry matter among roots and tops. The distribution of dry weight and shoot:root ratios for a range of densities is given in table 1. As density increased, the relative amounts of both roots and leaves decreased, while the amount of stem increased.

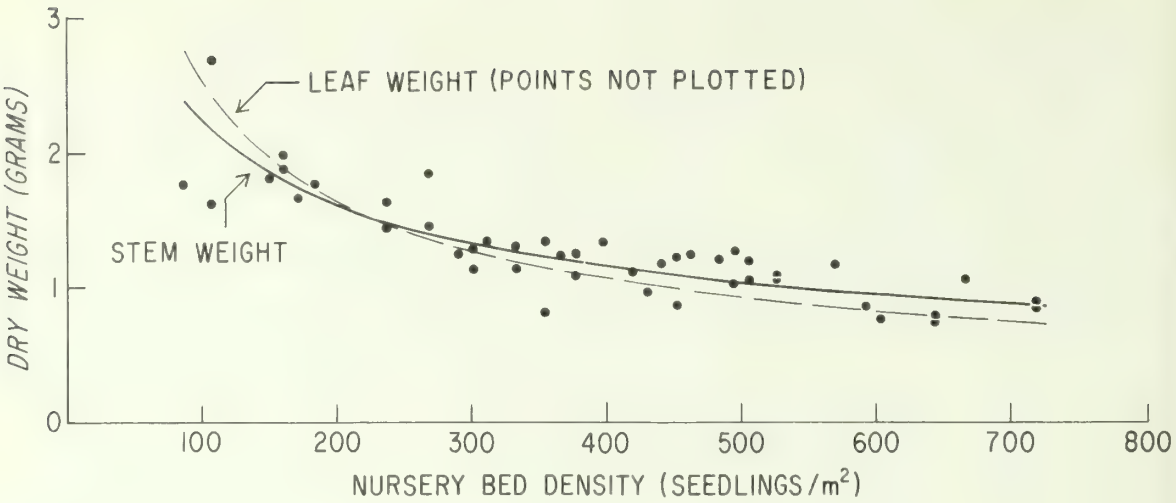

Figure 2.--Effect of nursery bed density on leaf weight and stem weight of loblolly pine seedlings.

Table 1.--Dry weight distribution among loblolly pine seedling parts and shoot:root ratios at different seedling densities

Seedling density (No./m²)	Proportion of total dry weight in			Shoot:root ratio
	Roots	Stems	Leaves	
	- - - - - Percent - - - - -			
100	29.2	33.2	37.6	2.4
200	27.1	36.1	36.8	2.7
400	25.1	39.1	35.8	2.9
600	24.2	40.5	35.3	3.1

Roots made up the smallest proportion of the total in all densities. Shoot:root ratio increased as seedling density increased.

The density variable used in the analysis was the number of seedlings on each plot at time of harvest. There was some mortality in the middle and upper densities, ranging from 5 to 15 percent, but the relationship to density was not consistent. The small size of the dead trees indicated that most of them had died early in the season and had had little effect on the growth of the survivors.

Each of the leaf variables was tested for its relationship to seedling weight by the function: Log_{10} seedling weight = a + b log_{10} leaf variable.

Leaf weight was most highly correlated with seedling weight, followed by leaf area, leaf thickness, and length (table 2). Thickness and length accounted for only a small part of the variation in dry weight. All four variables were statistically significant at the 1-percent level.

Table 2.--Relationships between seedling dry weight and leaf variable (X) as described by the regression: $\text{Log}_{10}\ Y = a + b\ \text{log}_{10}\ X$

Leaf variable X	Constant a	Coefficient b	r^2
Dry weight, g	0.4512	0.9152	0.96
Area, dm^2	- .0749	.8438	.79
Thickness, g/cm	1.0405	.9912	.49
Length, cm	- .4351	.8478	.14

The leaf variables were also significantly related to seedling density (table 3). Leaf weight was most closely correlated with density; length the least.

Table 3.--Relationships between various leaf variables (Y) and number of seedlings per m^2 (X) as described by the regression: $\text{Log}_{10}\ Y = a + b\ \text{log}_{10}\ X$

Leaf variable Y	Constant a	Coefficient b	r^2
Dry weight, g	1.6632	-0.6295	0.83
Area, dm^2	2.1199	- .5616	.67
Thickness, g/cm	.2545	- .3104	.53
Length, cm	1.4778	- .1402	.27

The density variable was combined with the leaf variables in a series of multiple regressions to determine if any combination would account for more variation in dry weight than either density or the leaf variables alone. We found that the addition of either leaf dry weight or leaf area to the density

regression significantly improved the prediction of dry weight over that provided by density alone. Leaf area increased the R^2 of the density regression from 0.83 to 0.89, and leaf weight increased it to 0.96. These regressions are:

$$\text{Log}_{10} \text{ seedling weight} = 1.1274 - 0.3565 \log_{10} \text{density} + 0.4151 \log_{10} \text{leaf area}; \; R^2 = 0.89$$

$$\text{Log}_{10} \text{ seedling weight} = 0.6457 - 0.0741 \log_{10} \text{density} + 0.8188 \log_{10} \text{leaf weight}; \; R^2 = 0.96$$

Leaf weight by itself (table 2) accounted for as much or more variation in seedling dry weight as any of the other single or multiple regressions ($r^2 = 0.96$). In the presence of leaf weight, the density variable was not significant. Neither leaf thickness nor needle length made a significant contribution to the density regression.

DISCUSSION

Observation and research have shown that as stand density in number of plants increases, there is a progressive decrease in average size of the individual plants, as well as changes in morphological and physiological characteristics (Switzer and Nelson 1963; van den Driessche 1971; Wilson and Campbell 1972). Our data also followed these trends. These phenomena are usually attributed to increasing competition for light, nutrients, and water--as more plants are crowded onto an area each plant gets a smaller and smaller share of the environment.

Our study does not permit us to examine the relative importance of competition for individual environmental factors. However, changes in crown morphology with seedling density, and correlations between leaf attributes and seedling dry weight both point to photosynthesis as being the primary physiological process involved. Seedling leaf weight, a measure of the photosynthesizing mass; leaf area, a measure of the light CO_2 absorbing surface; and leaf thickness, which varies in response to shade, were all reduced as density increased. Variation in these attributes has been found to be associated with rate and amount of dry matter production in many species of plants (Watson 1952). Switzer and Nelson (1963) in their study of the effect of nursery bed density and fertility in loblolly pine found that foliage weight and stem and root weight at time of outplanting were all positively correlated with height the trees attained 3 years later.

The importance of leaf length to dry matter production is not clear. Possibly it is merely another symptom of the effects of density stress on seedling growth.

The percentage of the seedling in leaf dry weight (table 1) expresses the proportion of photosynthetic tissue to the respiratory mass of the whole seedling. It also indicates how much of the dry matter produced has gone into building up photosynthetic tissue. As density increased and the relative amount of leaf tissue decreased, the absolute amount of dry matter produced per seedling also decreased (fig. 1). The root system is also involved in this relationship. The ratio of leaf weight to root weight increased from 1.29 at 100 seedlings per m^2 to 1.45 at 600 per m^2. An increase in the ratio would reduce both the quantity and rate of water and nutrient supply to the leaves, and this would in turn lower their efficiency and rate of growth. A similar interpretation can be given to the shoot:root ratio.

Results of this study indicate that the effects of increasing stand density on seedling growth are more complex than a simple reduction in overall growth from competition. All of the plant characters measured responded to changes in density, but the reduction in seedling leaf weight, area, length, and thickness with increasing density was primarily a response to low light intensities within the crown space. Reduced light intensity implies a reduction in photosynthesis and therefore in the production of dry matter. Competition for soil moisture and nutrients may have contributed to growth losses, but under the cultural conditions of the nursery bed it was probably not as limiting a factor as light. Evidence to support this hypothesis is provided by Harris and others (1972) for European white birch (Betula verrucosa Ehrh.), eucalyptus (Eucalyptus sideroxylon A. Cunn.), clammy hopseedbush (Dodonaea viscosa Jacq.), and sweetgum (Liquidambar styraciflua L.), and Tanaka and Timmis (1974) for Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco). These investigators studied the effects of stand density on seedlings grown in containers. The containers provided a constant soil volume and at the same time eliminated root competition between seedlings. In both studies, low container density (wide spacing) produced larger, heavier seedlings than high container density. Adequate moisture and nutrients were provided, so the only environmental factor for which there was active competition was light. In a study of stand density in cotton (Gossypium hirsutum L.) designed to separate the effects of root and crown competition, Rennie (1974) found that dry weight of 28-day-old plants was little affected by root competition, but that crown competition had a significant negative effect on growth.

Although not conclusive, our data together with the data reported in the literature provide evidence showing that reduced growth of seedlings in closely spaced stands where moisture and nutrients are not limiting is probably the result of competition for light within the crowns. However, when moisture and nutrients are also in short supply, they may be relatively more limiting to growth than light because they directly affect the physiological processes governing the ability of plants to utilize light.

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LITERATURE CITED

Evans, G. C.
1972. The quantitative analysis of plant growth. 734 p. Blackwell Sci. Publ., Oxford.

Harris , R. W., A. T. Leiser, P. L. Meel, D. Lung, N. W. Stice, and R. G. Maire
1972. Spacing of container-grown trees in the nursery. J. Am. Soc. Hortic. Sci. 97:503-506.

Jarvis, P. G., and M. S. Jarvis
1964. Growth rates of woody plants. Physiol. Plant. 17:654-666.

Kozlowski, T. T., and F. X. Schumacher
1943. Estimation of stomated foliar surface of pines. Plant Physiol. 18:122-127.

Ledig, F. T., and T. O. Perry
1969. Net assimilation rate and growth in loblolly pine seedlings. For. Sci. 15:431-438.

Rennie, J. C.
1974. Some effects of competition and density of plants on dry weight produced. Ann. Bot. 38:1003-1012.

Switzer, G. L., and L. E. Nelson
1963. Effects of nursery fertility and density on seedling characteristics, yield, and field performance of loblolly pine (Pinus taeda L.). Soil Sci. Soc. Am. Proc. 27:461-464.

Tanaka, Y., and R. Timmis
1974. Effects of container density on growth and coldhardiness of Douglas-fir seedlings. In R. W. Tinus, W. I. Stein, and W. E. Balmer [eds.] , Proceedings North American containerized forest tree seedling symposium. Great Plains Agric. Counc. Publ. 68: 181-186.

van den Driessche, R.
1971. Growth of one-year-old Douglas-fir plants at four spacings. Ann. Bot. 35:117-126.

Wareing, P. F.
1964. Tree physiology in relation to genetics and breeding. Unasylva 18:61-70.

Watson, D. J.
1952. The physiological basis of variation in yield. Adv. Agron. 4:101-145.

Wilson, B. C., and R. K. Campbell
1972. Seedbed density influences height diameter, and dry weight of 3-0 Douglas-fir. Tree Plant. Notes 23:1-4.

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SDA Forest Service Research Paper SE-162 January 1977

ABOVEGROUND BIOMASS OF LONGLEAF PINE IN A NATURAL SAWTIMBER STAND IN SOUTHERN ALABAMA

by

Michael A. Taras

and

Alexander Clark III

Forest Service - U.S. Department of Agriculture
Southeastern Forest Experiment Station
Asheville, North Carolina

Conversion factors: English to metric

Multiply		By		To Obtain
Inches	x	2.540	=	centimeters
Feet	x	.3048	=	meters
Pounds	x	.4536	=	kilograms
Cubic feet	x	.02832	=	cubic meters
Pounds per cubic foot	x	16.02	=	kilograms per cubic meter

All English units of measure in this report can be converted to metric units by multiplying by the appropriate conversion factor listed above.

ABOVEGROUND BIOMASS OF LONGLEAF PINE IN A NATURAL SAWTIMBER STAND IN SOUTHERN ALABAMA[1]

by

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Abstract.--Longleaf pine trees 6 to 18 inches d.b.h. were selected from a natural, uneven-aged sawtimber stand in southern Alabama to determine weight and volume of aboveground biomass. On the average, 85 percent of the dry weight of the total tree was wood, 11 percent was bark, and 4 percent was needles. The average tree sampled had 88 percent of its wood in the stem and 12 percent in the crown. Trends in biomass proportions are discussed. Specific gravity, moisture content, and green weight per cubic foot are presented for the total tree and its components. Tables developed with regression equations predict weight and cubic foot volume of the total tree and its components by d.b.h. and total height classes.

Keywords: Pinus palustris Mill., weight, volume, prediction equations, component proportions, biomass.

This is the third in a series of reports on the aboveground biomass of southern pine sawtimber trees. It contains information on longleaf pine (Pinus palustris Mill.). The first two papers were on loblolly pine (Pinus taeda L.)[2] and shortleaf pine (P. echinata Mill.).[3]

This paper reports weights and volumes of various tree components (wood, bark, crown, branches, and foliage) as well as equations for predicting these components. The term total tree in this study refers only to the aboveground portion of the tree and does not include stump and roots.

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[1]This study was conducted by the Southeastern Forest Experiment Station in cooperation with and through the financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System. Field personnel were provided by the Conecuh National Forest.

[2]Taras, Michael A., and Alexander Clark III. 1975. Aboveground biomass of loblolly pine in a natural, uneven-aged sawtimber stand in central Alabama. Tappi 58(2): 103-105.

[3]Clark, Alexander III, and Michael A. Taras. 1976. Biomass of shortleaf pine in a natural sawtimber stand in northern Mississippi. USDA For. Serv. Res. Pap. SE-146, 32 p. Southeast. For. Exp. Stn., Asheville, N.C.

PROCEDURE

FIELD

A stratified random sample of 47 trees was selected from a natural, uneven-aged longleaf pine stand on the Conecuh National Forest in southern Alabama. Site index (age 50) averaged 80. Three to twelve trees from each even-inch d.b.h. class from 6 to 18 inches were selected. The sample trees had an average d.b.h. of 13.2 inches and an average total height of 80 feet. Means and ranges of tree measurements are shown in table 1.

After felling and limbing, the main stem of each tree was bucked into merchantable saw logs and pulpwood. Saw logs 8 to 16 feet long were cut from the main stem to a 6-inch d.i.b. or merchantable top. All material above saw-log merchantability to a 2-inch top was classed as pulpwood. The crown was cut up and segregated into four categories: [1] large branches ($\geq$ 2.0 inches d.o.b.), [2] medium branches ($\geq$ 0.6 and $\leq$ 1.9 inches d.o.b.), [3] small branches ($\leq$ 0.5 inches d.o.b.), and [4] needles. The tip of the stem (2 inches d.i.b. to top) was included as branch material in the analysis. All crown material and pulpwood were weighted to the nearest 0.25 pound. Saw logs were weighed individually.

Moisture content and specific gravity of wood and bark were determined from disks removed at the butt of each tree, at each saw-log bucking point, and at points where d.i.b. measured 4 and 2 inches. Disks were also taken from branches randomly selected from each branch category. A sample of needles was selected for determination of needle moisture content. The disks were weighed and calipered with and without bark immediately after being sawed. A representative sample of bark and wood was removed from each disk, weighed, and sealed in a polyethylene bag for laboratory analysis.

Table 1.--Means and ranges of measurements of longleaf pine in each d.b.h. class sampled

D.b.h. class (inches)	Sample trees	D.b.h.		Total height		Merchantable height[1/]		Age		Form class	
		Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
	Number	Inches		Feet				Years			
6	3	6.0	5.9 - 6.1	59	56-60	--	--	34	32-35	--	--
8	3	8.0	7.9 - 8.2	64	63-66	17	16-19	35	35-36	79	76-85
10	8	10.2	9.8 - 10.5	71	59-79	40	34-48	43	39-48	80	75-83
12	7	12.1	11.6 - 12.4	82	73-88	54	39-62	57	49-63	84	82-87
14	7	14.1	13.8 - 14.4	84	77-90	55	40-64	55	44-61	82	79-86
16	12	16.0	15.6 - 16.7	86	80-94	58	48-70	61	53-66	85	80-88
18	7	17.6	17.1 - 18.9	88	77-97	58	36-73	64	59-69	83	80-85
All classes	47	13.2	5.9 - 18.9	80	56-97	48	16-73	53	32-69	82	75-88

[1/] Height to 6-inch d.i.b. or merchantable top.

LABORATORY

Specific gravity was computed from green volume and ovendry weight. Moisture content samples were dried to a constant weight at 103° C, and moisture content was computed on an ovendry basis. Percentage of bark was determined on a weight basis from cross-section samples. Weighted values for moisture content, specific gravity, and percentage of bark in the stem, branches, and total tree were calculated by weighting disk values in proportion to the volume of the component each represented. Weighted moisture content values were used to convert component green weights to ovendry weights.

The following equation was used to calculate green weight per cubic foot separately for wood and bark on the basis of the weighted values for specific gravity and moisture content:

$$\text{Green weight per cubic foot} = \left(1 + \frac{\text{weighted moisture content in percent}}{100}\right) \times (62.4 \times \text{weighted specific gravity}) \qquad (1)$$

The green cubic foot volume of wood and bark was computed by dividing component weight by the component's green weight per cubic foot. Green cubic foot volume of wood and bark was computed by adding the green volume of wood to the green volume of bark.

ANALYSIS

Simple linear regression equations for predicting green and dry weight of wood, bark, and needles in the total tree and its components were developed with d.b.h., total height, merchantable height, crown length, crown ratio, and form class as independent variables. Equations were also developed to predict green cubic foot volume of wood and bark separately and combined.

The best independent variables examined were d.b.h. and total height. Thus, tree and component weights and volumes were estimated with the equation

$$Y = b_0 + b_1 D^2Th + e \qquad (2)$$

where:
- Y = weight or volume of component,
- D = d.b.h. in inches,
- Th = total tree height in feet,
- e = experimental error, and
- b_0, b_1 = constants.

Grouping of the data into D^2Th classes indicated that the variance of Y increased with increasing D^2Th. Thus, a logarithmic transformation was used to make the variance more nearly homogeneous and meet this basic assumption of regression analysis. The final form of the equation used to predict weight and volume of the total tree and each component sampled was

$$\text{Log}_{10}\ Y = b_0 + b_1\ \text{Log}_{10}\ (D^2Th) \qquad (3)$$

TOTAL TREE BIOMASS

Green and dry weight of the total tree and proportions of tree weight in wood, bark, and needles are shown in table 2. Green weight of the total tree ranged from 396 pounds for a 6-inch tree to 5,122 pounds for an 18-inch tree. On the average, the trees sampled had 85 percent of their dry weight in wood, 11 percent in bark, and 4 percent in needles. The proportion of tree weight in wood increased and the proportion in bark decreased as tree size increased from 6 to 12 inches d.b.h. and then remained relatively constant in trees 12 inches d.b.h. and larger. The proportion of tree weight in needles did not change consistently with tree size and averaged 4 percent. Proportions of the various tree components computed on a dry basis varied slightly from those computed on a green basis because of differences in component moisture content (table 2).

Table 2.--Average green and dry weight of the total tree and proportions of the tree in wood, bark, and needles for longleaf pine trees 6 to 18 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree green weight	Tree component proportions (green)			Total tree dry weight	Tree component proportions (dry)		
				Wood	Bark	Needles		Wood	Bark	Needles
	Feet	Number	Pounds	- - - Percent - - -			Pounds	- - - Percent - - -		
6	59	3	396	79	14	7	213	78	17	5
8	64	3	859	79	13	8	451	79	15	6
10	71	8	1,378	83	11	6	740	82	13	5
12	82	7	2,252	85	10	5	1,242	85	11	4
14	84	7	3,076	84	10	6	1,718	84	11	5
16	86	12	4,268	86	9	5	2,333	86	10	4
18	88	7	5,122	84	11	5	2,765	84	12	4
Average	--	--	2,961	85	10	5	1,617	85	11	4

When the trees were viewed as being composed of stem and crown, proportion of the tree weight in stem material decreased and proportion in crown material (branches plus needles) increased with increasing tree size (table 3). Proportion of tree dry weight in crown material ranged from 13 percent in the small trees to 20 percent in the large trees and averaged 17 percent. This average value is within 1 percent of the averages previously reported in this series for loblolly pine (16 percent) and shortleaf pine (18 percent). As with the other two species, the increase in proportion of crown material was due to an increase in proportion of branch material and not to an increase in the proportion of needles.

The green and dry weight of all wood in the tree and the distribution of wood throughout the tree are presented in table 4. On the average, the trees had 89 percent of their dry wood weight in the main stem (to a 2-inch top) and 11 percent in branches. The proportion of wood in the main stem decreased and that in the branches increased as tree size increased. The increase in proportion of wood in branches was due to an increase in large branch material in

Table 3.--Average green and dry weight of the total tree and proportions of the tree in main stem[1/] and crown (branches and needles) for longleaf pine trees 6 to 18 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree green weight	Tree component proportions (green)			Total tree dry weight	Tree component proportions (dry)		
				Stem	Crown			Stem	Crown	
					Branches	Needles			Branches	Needles
	Feet	Number	Pounds	- - - Percent - - -			Pounds	- - - Percent - - -		
6	59	3	396	85	8	7	213	87	8	5
8	64	3	859	84	8	8	451	85	9	6
10	71	8	1,378	84	10	6	740	86	9	5
12	82	7	2,252	85	10	5	1,242	86	10	4
14	84	7	3,076	82	12	6	1,718	84	12	4
16	86	12	4,268	81	14	5	2,333	83	13	4
18	88	7	5,122	78	17	5	2,765	80	16	4
Average	--	--	2,961	81	14	5	1,617	83	13	4

[1/] Stem material to 2-inch d.i.b. top.

Table 4.--Average green and dry weight of wood in the total tree and distribution of wood in main stem[1/] and branches for longleaf pine trees 6 to 18 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree wood weight	Proportion of wood in--						
				Main stem			Branches			
				Saw log	Pulpwood	Total stem	Large	Medium	Small	All branches
	Feet	Number	Pounds	- - - - - - - - - - - - - - - - Percent - - - - - - - - - - - - - - - -						
				GREEN						
6	59	3	314	--	94	94	0	4	2	6
8	64	3	681	70	24	94	0	4	2	6
10	71	8	1,142	77	15	92	3	3	2	8
12	82	7	1,908	84	8	92	4	2	2	8
14	84	7	2,582	82	8	90	6	2	2	10
16	86	12	3,667	80	8	88	8	2	2	12
18	88	7	4,306	78	7	85	10	3	2	15
Average	--	--	2,504	79	9	88	7	3	2	12
				DRY						
6	59	3	167	--	94	94	0	4	2	6
8	64	3	357	74	20	94	0	4	2	6
10	71	8	610	80	13	93	3	3	1	7
12	82	7	1,054	86	7	93	3	2	2	7
14	84	7	1,448	83	8	91	5	2	2	9
16	86	12	2,009	82	7	89	7	2	2	11
18	88	7	2,325	80	6	86	10	3	1	14
Average	--	--	1,369	81	8	89	6	3	2	11

[1/] Stem material to 2-inch d.i.b. top.

larger trees. The proportion of wood in the pulpwood section of a tree decreased and proportion in the saw-log section increased as tree size increased. On the average, the trees contained 81 percent of their dry wood in saw-log material and 8 percent in pulpwood.

The weight and distribution of bark in the tree are presented in table 5. As tree size increased, the proportion of bark in the main stem decreased and the proportion of bark in the branches increased. This increase in proportion of bark in branches was due to an increase in the proportion of large branches in large trees. On the average, 58 percent of all dry bark in the tree was in saw-log material, 7 percent was in pulpwood, and 35 percent was in branches.

Table 5.--Average green and dry weight of bark in the total tree and distribution of bark in main stem[1/] and branches for longleaf pine trees 6 to 18 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree bark weight	Proportion of bark in--						
				Main stem			Branches			
				Saw log	Pulpwood	Total stem	Large	Medium	Small	All branches
	Feet	Number	Pounds	Percent						
				GREEN						
6	59	3	56	--	78	78	0	7	15	22
8	64	3	110	55	19	74	0	9	17	26
10	71	8	157	59	12	71	6	10	13	29
12	82	7	221	59	8	67	7	9	17	33
14	84	7	321	56	7	63	10	8	19	37
16	86	12	383	56	5	62	12	8	18	38
18	88	7	538	53	5	58	16	10	16	42
Average	--	--	296	55	8	63	11	9	17	37
				DRY						
6	59	3	36	--	79	79	0	8	13	21
8	64	3	66	58	17	75	0	9	16	25
10	71	8	96	64	10	74	5	9	12	26
12	82	7	134	62	7	69	6	8	17	31
14	84	7	194	59	7	66	9	7	18	34
16	86	12	232	58	6	64	12	7	17	36
18	88	7	320	56	5	61	14	9	16	39
Average	--	--	179	58	7	65	11	8	16	35

[1/] Stem material to 2-inch d.i.b. top.

CROWN BIOMASS

When the crown was analyzed as a separate entity composed of branchwood, branchbark, and needles, the proportion of crown weight in wood increased, the proportion in needles decreased, and the proportion in bark decreased as tree size increased (table 6). On the average, 53 percent of the dry weight of the crown was in wood, 22 percent was in bark, and 25 percent was in needles.

Branches made up 8 to 16 percent of the dry weight of the total tree, depending on tree size (table 3). On the average, 24 percent of the branch dry weight was in small branches, 24 percent was in medium branches, and 52 percent was in large branches. This size distribution of branches varied greatly with tree size (fig. 1). The proportion of large branches increased rapidly with increasing tree size, and the proportion of medium and small branches decreased with increasing tree size. When branches were separated into wood and bark, large branches averaged 83 percent wood and 17 percent bark, medium branches averaged 71 percent wood and 29 percent bark, and small branches averaged 42 percent wood and 58 percent bark.

Table 6.--Average green and dry weight of the crown and proportions of the crown in wood, bark, and needles for longleaf pine trees 6 to 18 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Crown weight (green)	Crown proportion (green)--			Crown weight (dry)	Crown proportion (dry)--		
				Branch-wood	Branch-bark	Needles		Branch-wood	Branch-bark	Needles
	Feet	Number	Pounds	- - - Percent - - - -			Pounds	- - - - Percent - - - -		
6	59	3	58	35	22	43	28	36	28	36
8	64	3	141	31	21	48	66	33	24	43
10	71	8	214	42	21	37	103	43	24	33
12	82	7	348	44	21	35	173	45	24	31
14	84	7	557	48	21	31	279	49	24	27
16	86	12	802	55	18	27	389	55	21	24
18	88	7	1,148	56	20	24	562	57	22	21
Average	--	--	560	52	19	29	274	53	22	25

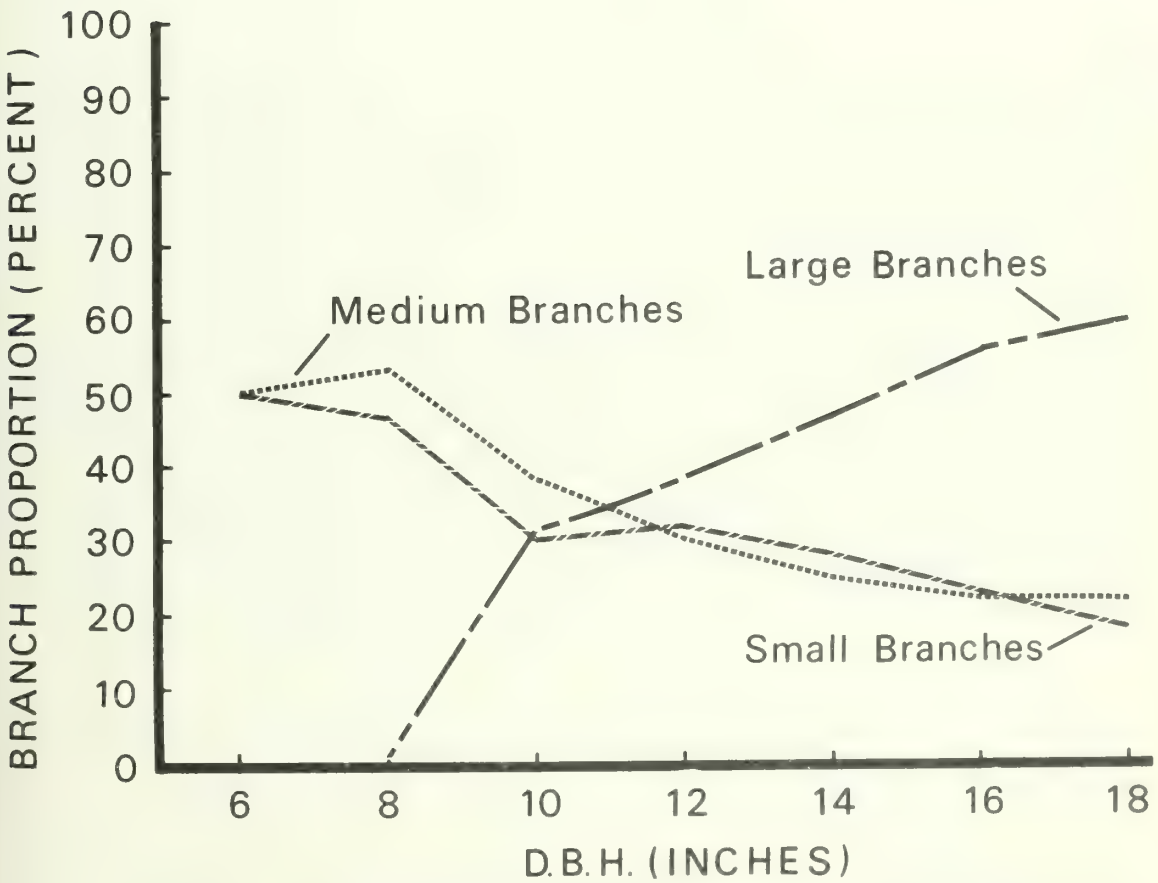

Figure 1.--Proportion of branches in crown by tree size.

MAIN STEM BIOMASS

When the main stem was analyzed separately, the proportion of stem weight in wood increased and the proportion in bark decreased as tree size increased (table 7). On the average, 91 percent of the dry weight of the stem was wood and 9 percent was bark. Similar proportions of wood and bark in the main stem were previously reported in this series for loblolly and shortleaf pines.

Table 7.--Average green and dry weight of the stem [1/] and proportions of the stem in wood and bark for longleaf pine trees 6 to 18 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Main stem weight (green)	Stem proportions in green--		Main stem weight (dry)	Stem proportions in dry--	
				Wood	Bark		Wood	Bark
	Feet	Number	Pounds	- -Percent- -		Pounds	- -Percent- -	
6	59	3	338	87	13	185	85	15
8	64	3	718	89	11	384	87	13
10	71	8	1,164	90	10	636	89	11
12	82	7	1,904	92	8	1,069	91	9
14	84	7	2,519	92	8	1,439	91	9
16	86	12	3,466	93	7	1,944	92	8
18	88	7	3,974	92	8	2,201	91	9
Average	--	--	2,401	92	8	1,343	91	9

[1/] Stem material to 2-inch d.i.b. top.

PHYSICAL PROPERTIES

Wood and bark specific gravity, moisture content, and green weight per cubic foot for the total tree and its components are presented in table 8. Wood specific gravity for the total tree averaged 0.552--the same as the average specific gravity reported for the species in southeastern Alabama.[4] Wood specific gravity for pulpwood averaged 0.509, which is considerably lower than the average for the saw-log portion of the tree and slightly higher than that for the branches. Bark specific gravity was consistently lower than wood specific gravity, averaging 0.401 for the total tree, 0.405 for the main stem, and 0.393 for branches. Bark specific gravity in all tree components was higher for longleaf pine than has been reported previously in this series for shortleaf or loblolly pines.

Wood moisture content averaged 84 percent for the total tree, 82 percent for the main stem, and 103 percent for the branches (table 8). Wood moisture content was considerably higher for pulpwood (106 percent) than for saw logs (79 percent).

[4] U.S. Forest Products Laboratory. 1972 (rev. 1975). Properties of major southern pines. Part I - Wood density survey, by H. E. Wahlgren and D. R. Schumann. Part II - Structural properties and specific gravity, by B. A. Bendtsen, R. L. Ethington, and W. L. Galligan. USDA For. Serv. Res. Pap. FPL 176-177, 76 p. U.S. For. Prod. Lab., Madison, Wis.

Table 8.--Average wood and bark specific gravity, moisture content, and weight per cubic foot for longleaf pine trees and tree components

Tree component	Average and standard deviation		
	Specific gravity	Moisture content	Green weight per cubic foot
		Percent	Pounds
	WOOD		
Total tree	0.552 ± 0.029	84 ± 8	63.3 ± 2.2
Saw log	.565 ± .034	79 ± 8	63.1 ± 2.5
Pulpwood	.509 ± .043	106 ± 16	65.1 ± 2.5
Main stem	.558 ± .031	82 ± 8	63.3 ± 2.4
Branches	.489 ± .029	103 ± 12	61.8 ± 3.0
	BARK		
Total tree	.401 ± .022	65 ± 7	41.3 ± 2.4
Saw log	.407 ± .025	57 ± 8	39.8 ± 2.8
Pulpwood	.390 ± .029	82 ± 14	44.1 ± 4.1
Main stem	.405 ± .026	59 ± 7	40.2 ± 2.8
Branches	.393 ± .028	78 ± 12	43.4 ± 2.7

On a total-tree basis, bark moisture content averaged 65 percent, which was lower than the corresponding value for wood (table 8). Bark moisture content was also lower for saw logs (57 percent) than for pulpwood (82 percent) or branches (78 percent). The higher moisture content in branches and pulpwood sections of the tree reflected the differences in the ratio of inner bark to outer bark and the differences in bark thickness in various parts of the tree.

Average wood weight per cubic foot did not vary greatly among tree components (table 8). Average green weight per cubic foot was lower for saw logs (63.1 pounds) than for pulpwood (65.1 pounds). Nevertheless, saw logs contained 2.7 pounds more wood per cubic foot than did pulpwood because of their higher specific gravity.

Bark was consistently lower in green weight per cubic foot than wood (table 8). Bark green weight per cubic foot averaged 41.3 pounds for the total tree, 39.8 pounds for saw logs, 44.1 pounds for pulpwood, and 43.4 pounds for branches. Branchbark weighed more per cubic foot than did the stembark because of its higher moisture content (78 percent vs. 59 percent). Green weight per cubic foot of wood and bark combined averaged 60.8 pounds for the total tree, 61.3 pounds in the main stem, and 56.3 pounds in branch material.

EQUATIONS

Equations were developed to predict weight and volume of the total tree and its components on the basis of the biomass of the 47 trees sampled. Those for predicting green and dry weights are in table 9, and those for predicting green cubic foot volumes are in table 10. Also included in tables 9 and 10 are the coefficient of determination and standard error of estimate for each equation. In most cases, the coefficients of determination indicate a high degree of linear association between the independent variable (D^2Th) and component

Table 9.--Regression equations for estimating green and dry weight of aboveground biomass of natural longleaf pine trees and tree components with d.b.h. and total height as independent variables

Weight (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]
COMPLETE TREE (INCLUDING NEEDLES)[3/]			
Green	$\text{Log}_{10} Y = -0.68988 + 0.99194 \text{ Log}_{10} D^2Th$	0.99	0.031
Dry	$\text{Log}_{10} Y = -0.99717 + 1.00242 \text{ Log}_{10} D^2Th$	.99	.036
COMPLETE TREE (EXCLUDING NEEDLES)[3/]			
Green	$\text{Log}_{10} Y = -0.74607 + 0.99947 \text{ Log}_{10} D^2Th$	.99	.030
Dry	$\text{Log}_{10} Y = -1.03965 + 1.00795 \text{ Log}_{10} D^2Th$	.99	.035
ALL WOOD IN TREE[3/]			
Green	$\text{Log}_{10} Y = -0.88747 + 1.02133 \text{ Log}_{10} D^2Th$	.99	.031
Dry	$\text{Log}_{10} Y = -1.21543 + 1.03675 \text{ Log}_{10} D^2Th$	.99	.038
ALL BARK IN TREE[3/]			
Green	$\text{Log}_{10} Y = -1.05087 + 0.84066 \text{ Log}_{10} D^2Th$	.96	.056
Dry	$\text{Log}_{10} Y = -1.20218 + 0.82474 \text{ Log}_{10} D^2Th$	.96	.054
WOOD AND BARK IN SAW-LOG PORTION OF STEM FOR TREES > 9.5 INCHES D.B.H.[4/]			
Green	$\text{Log}_{10} Y = -0.97687 + 1.02760 \text{ Log}_{10} D^2Th$	.96	.041
Dry	$\text{Log}_{10} Y = -1.22689 + 1.02819 \text{ Log}_{10} D^2Th$	.96	.045

continued

Table 9.--Regression equations for estimating green and dry weight of aboveground biomass of natural longleaf pine trees and tree components with d.b.h. and total height as independent variables (continued)

Weight (Y)	Regression equation[1]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2]
WOOD IN SAW-LOG PORTION OF STEM FOR TREES > 9.5 INCHES D.B.H.[4]			
Green	$\text{Log}_{10} Y = -1.08665 + 1.04530 \text{ Log}_{10} D^2Th$	0.96	0.043
Dry	$\text{Log}_{10} Y = -1.36758 + 1.05208 \text{ Log}_{10} D^2Th$	.95	.048
BARK IN SAW-LOG PORTION OF STEM FOR TREES > 9.5 INCHES D.B.H.[4]			
Green	$\text{Log}_{10} Y = -1.26502 + 0.83155 \text{ Log}_{10} D^2Th$	.92	.051
Dry	$\text{Log}_{10} Y = -1.35097 + 0.80530 \text{ Log}_{10} D^2Th$	.89	.057
WOOD AND BARK IN STEM FROM STUMP TO 2-INCH D.I.B. TOP[3]			
Green	$\text{Log}_{10} Y = -0.65002 + 0.96146 \text{ Log}_{10} D^2Th$	.99	.028
Dry	$\text{Log}_{10} Y = -0.96015 + 0.97497 \text{ Log}_{10} D^2Th$	.99	.034
WOOD IN STEM FROM STUMP TO 2-INCH D.I.B. TOP[3]			
Green	$\text{Log}_{10} Y = -0.78784 + 0.98563 \text{ Log}_{10} D^2Th$	.99	.030
Dry	$\text{Log}_{10} Y = -1.13120 + 1.00588 \text{ Log}_{10} D^2Th$	.99	.037
BARK IN STEM FROM STUMP TO 2-INCH D.I.B. TOP[3]			
Green	$\text{Log}_{10} Y = -0.77468 + 0.72855 \text{ Log}_{10} D^2Th$	.96	.046
Dry	$\text{Log}_{10} Y = -0.93976 + 0.71954 \text{ Log}_{10} D^2Th$	.95	.053

continued

Table 9.--Regression equations for estimating green and dry weight of aboveground biomass of natural longleaf pine trees and tree components with d.b.h. and total height as independent variables (continued)

Weight (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{Y.X}$)[2/]
CROWN WEIGHT (INCLUDING BRANCHWOOD, BRANCHBARK, AND NEEDLES)[3/]			
Green	$\text{Log}_{10} Y = -2.00999 + 1.12764 \text{ Log}_{10} D^2Th$	0.91	0.111
Dry	$\text{Log}_{10} Y = -2.37618 + 1.14054 \text{ Log}_{10} D^2Th$	.90	.118
NEEDLES[3/]			
Green	$\text{Log}_{10} Y = -1.46928 + 0.87586 \text{ Log}_{10} D^2Th$	.90	.091
Dry	$\text{Log}_{10} Y = -1.90676 + 0.89244 \text{ Log}_{10} D^2Th$	.90	.094
WOOD AND BARK IN ALL BRANCH MATERIAL[3/]			
Green	$\text{Log}_{10} Y = -2.72222 + 1.25770 \text{ Log}_{10} D^2Th$	.90	.134
Dry	$\text{Log}_{10} Y = -2.95713 + 1.24480 \text{ Log}_{10} D^2Th$	.89	.141
WOOD IN ALL BRANCH MATERIAL[3/]			
Green	$\text{Log}_{10} Y = -3.22660 + 1.34140 \text{ Log}_{10} D^2Th$	.90	.147
Dry	$\text{Log}_{10} Y = -3.51387 + 1.33673 \text{ Log}_{10} D^2Th$	.88	.157
BARK IN ALL BRANCH MATERIAL[3/]			
Green	$\text{Log}_{10} Y = -2.49769 + 1.07628 \text{ Log}_{10} D^2Th$	.90	.116
Dry	$\text{Log}_{10} Y = -2.72978 + 1.07216 \text{ Log}_{10} D^2Th$	.89	.120

[1/] $\text{Log}_{10} Y = b_0 + b_1 \text{ Log}_{10} D^2Th$

where: Y = weight of tree or component in pounds,
D = d.b.h. in inches,
Th = total height in feet.

[2/] Standard error of estimate in Log_{10} form.
[3/] Regression equations based on 47 trees 6 to 18 inches d.b.h.
[4/] Regression equations based on 41 trees 10 to 18 inches d.b.h.

Table 10.--Regression equations for estimating green cubic foot volume of the aboveground biomass of natural longleaf pine trees and tree components with d.b.h. and total height as independent variables

Cubic foot volume (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]
TOTAL TREE[3/]			
Wood	$\text{Log}_{10} Y = -2.80224 + 1.04936 \text{ Log}_{10} D^2Th$	0.99	0.027
Bark	$\text{Log}_{10} Y = -2.54434 + 0.81138 \text{ Log}_{10} D^2Th$	.95	.061
Wood & bark	$\text{Log}_{10} Y = -2.54553 + 1.00570 \text{ Log}_{10} D^2Th$	.99	.026
STEM FROM STUMP TO SAW-LOG TOP FOR TREES > 9.5 INCHES D.B.H.[4/]			
Wood	$\text{Log}_{10} Y = -3.00060 + 1.07344 \text{ Log}_{10} D^2Th$	.97	.040
Bark	$\text{Log}_{10} Y = -2.88643 + 0.83568 \text{ Log}_{10} D^2Th$	.89	.059
Wood & bark	$\text{Log}_{10} Y = -2.82198 + 1.04378 \text{ Log}_{10} D^2Th$	.97	.037
STEM FROM STUMP TO 2-INCH D.I.B. TOP[3/]			
Wood	$\text{Log}_{10} Y = -2.72558 + 1.01904 \text{ Log}_{10} D^2Th$	.99	.028
Bark	$\text{Log}_{10} Y = -2.25358 + 0.69804 \text{ Log}_{10} D^2Th$	.94	.056
Wood & bark	$\text{Log}_{10} Y = -2.47035 + 0.97145 \text{ Log}_{10} D^2Th$	.99	.025
ALL BRANCH MATERIAL[3/]			
Wood	$\text{Log}_{10} Y = -4.84899 + 1.30101 \text{ Log}_{10} D^2Th$	.89	.146
Bark	$\text{Log}_{10} Y = -4.10690 + 1.07007 \text{ Log}_{10} D^2Th$	.89	.119
Wood & bark	$\text{Log}_{10} Y = -4.26121 + 1.20985 \text{ Log}_{10} D^2Th$	.90	.131

[1/] $\text{Log}_{10} Y = b_0 + b_1 \text{ Log}_{10} D^2Th$

where: Y = cubic feet of tree or component,
D = d.b.h. in inches,
Th = total height in feet.

[2/] Standard error of estimate in Log_{10} form.

[3/] Regression equations based on 47 trees 6 to 18 inches d.b.h.

[4/] Regression equations based on 41 trees 10 to 18 inches d.b.h.

weight or volume. Poorest associations occurred in equations developed to predict branch weight and volume. Crown components varied more than other tree components.

YIELD TABLES

The equations in tables 9 and 10 were used to develop tables of biomass weight and volume. These tables of predicted yields are presented in the Appendix. Predicted green and dry weights of wood, bark, and needles in the total tree, main stem, and crown are presented in tables 11 through 21 by d.b.h. and total height classes. Predicted green cubic foot volumes of wood and bark in the total tree, main stem, and branches are presented in tables 22 through 24.

Trees with the same d.b.h. and total height can vary considerably in weight and volume because of differences in crown size, moisture content, specific gravity, and taper. The yield tables presented in the Appendix should not be used indiscriminately over the range of longleaf pine without testing. Rather, they should be applied only to natural, closed stands which are similar in age, taper rate, and wood properties to the trees sampled.

Appendix

Table 11.--Predicted weight of total tree (wood, bark, and needles) for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
	GREEN[3/]						
6	346	415	483	552			
7	470	563	656	749			
8	612	734	855	976	1,097		
9	774	927	1,080	1,233	1,386	1,539	
10	953	1,142	1,331	1,520	1,708	1,896	2,084
11	1,152	1,380	1,608	1,836	2,064	2,291	2,518
12	1,369	1,640	1,911	2,182	2,452	2,722	2,992
13	1,604	1,923	2,240	2,557	2,874	3,191	3,507
14	1,859	2,227	2,595	2,962	3,330	3,696	4,063
15	2,131	2,554	2,976	3,397	3,818	4,239	4,659
16		2,902	3,382	3,861	4,340	4,818	5,295
17		3,273	3,814	4,354	4,894	5,433	5,972
18			4,272	4,877	5,482	6,086	6,689
19			4,756	5,430	6,102	6,775	7,446
20			5,265	6,011	6,756	7,500	8,244
	DRY[4/]						
6	184	221	258	296			
7	251	302	352	403			
8	328	394	460	526	592		
9	416	499	583	666	750	833	
10	514	617	720	823	926	1,029	1,132
11	622	747	871	996	1,121	1,246	1,371
12	740	889	1,037	1,186	1,335	1,483	1,632
13	869	1,044	1,218	1,393	1,567	1,742	1,916
14	1,009	1,211	1,413	1,616	1,818	2,021	2,223
15	1,158	1,390	1,623	1,855	2,088	2,320	2,553
16		1,583	1,847	2,111	2,376	2,641	2,906
17		1,787	2,086	2,384	2,683	2,982	3,281
18			2,339	2,674	3,009	3,344	3,679
19			2,607	2,980	3,353	3,727	4,101
20			2,889	3,303	3,717	4,131	4,545

1/ Blocked-in area indicates range of data.
2/ Includes 1-foot stump allowance.
3/ $\text{Log}_{10} Y = -0.68988 + 0.99194 \text{ Log}_{10} D^2Th.$
4/ $\text{Log}_{10} Y = -0.99717 + 1.00242 \text{ Log}_{10} D^2Th.$

Table 12.--Predicted weight of all aboveground wood excluding bark for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
	GREEN[3/]						
6	274	330	386	442			
7	375	452	529	606			
8	493	593	695	796	898		
9	627	755	883	1,013	1,142	1,272	
10	777	936	1,096	1,256	1,416	1,577	1,738
11	944	1,137	1,331	1,526	1,721	1,916	2,112
12	1,128	1,358	1,590	1,822	2,055	2,289	2,523
13	1,328	1,600	1,872	2,146	2,420	2,695	2,971
14	1,545	1,861	2,178	2,497	2,816	3,136	3,456
15	1,779	2,143	2,508	2,875	3,242	3,610	3,979
16		2,445	2,861	3,280	3,699	4,119	4,540
17		2,767	3,239	3,712	4,186	4,662	5,139
18			3,640	4,172	4,705	5,239	5,775
19			4,065	4,659	5,254	5,851	6,449
20			4,514	5,173	5,835	6,498	7,162
	DRY[4/]						
6	144	174	205	235			
7	199	240	282	324			
8	262	317	372	427	482		
9	335	404	474	545	616	687	
10	416	503	590	678	766	854	943
11	507	613	719	826	933	1,041	1,149
12	608	734	861	989	1,118	1,247	1,376
13	717	867	1,017	1,168	1,319	1,472	1,625
14	837	1,011	1,186	1,362	1,539	1,716	1,894
15	965	1,166	1,368	1,571	1,775	1,980	2,186
16		1,333	1,564	1,796	2,029	2,264	2,499
17		1,511	1,773	2,037	2,301	2,567	2,833
18			1,997	2,293	2,591	2,890	3,190
19			2,233	2,565	2,898	3,233	3,568
20			2,484	2,853	3,223	3,595	3,969

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -0.88747 + 1.02133 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -1.21543 + 1.03675 \text{ Log}_{10} D^2Th.$

Table 13.--Predicted weight of all aboveground bark for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
	GREEN[3/]						
6	48	57	64	72			
7	63	73	83	93			
8	79	92	104	117	129		
9	96	112	127	142	157	172	
10	114	133	152	170	188	205	222
11	134	157	178	199	220	241	261
12	156	181	206	231	255	279	302
13	178	207	236	264	292	319	345
14	202	235	267	299	330	361	391
15	226	264	300	336	371	405	439
16		294	335	375	414	452	490
17		326	371	415	458	500	542
18			408	457	504	551	597
19			447	500	552	603	653
20			487	545	602	658	712
	DRY[4/]						
6	30	35	40	45			
7	39	46	52	58			
8	49	57	64	72	79		
9	59	69	78	87	96	105	
10	71	82	93	104	115	125	135
11	83	96	109	122	134	146	158
12	95	111	126	140	155	169	183
13	109	126	144	160	177	193	208
14	123	143	162	181	200	218	235
15	138	160	182	203	224	244	264
16		178	202	226	249	271	294
17		197	223	249	275	300	324
18			246	274	302	329	356
19			268	300	330	360	390
20			292	326	359	392	424

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -1.05087 + 0.84066 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -1.20218 + 0.82474 \text{ Log}_{10} D^2Th.$

Table 14.--Predicted weight of needles for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
	GREEN[3/]						
6	24	28	32	36			
7	32	37	42	48			
8	40	47	54	60	67		
9	49	58	66	74	82	90	
10	59	69	79	89	99	108	118
11	70	82	94	105	117	128	139
12	81	95	109	122	136	149	162
13	93	110	125	141	156	171	186
14	106	125	143	160	178	195	212
15	120	141	161	181	201	220	239
16		158	180	203	225	246	268
17		175	201	225	250	274	298
18			222	249	276	303	329
19			244	274	304	333	362
20			267	300	332	364	396
	DRY[4/]						
6	10	12	13	15			
7	13	15	18	20			
8	17	20	22	25	28		
9	21	24	28	31	35	38	
10	25	29	33	38	42	46	50
11	29	35	40	45	50	55	59
12	34	40	46	52	58	64	69
13	40	47	53	60	67	74	80
14	45	53	61	69	76	84	91
15	51	60	69	78	86	95	103
16		68	77	87	97	106	116
17		75	86	97	108	119	129
18			96	108	120	131	143
19			105	119	132	145	158
20			115	130	144	159	173

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -1.46928 + 0.87586\ \text{Log}_{10}\ D^2Th.$
[4/] $\text{Log}_{10}\ Y = -1.90676 + 0.89244\ \text{Log}_{10}\ D^2Th.$

Table 15.--Predicted weight of wood and bark in main stem to 2-inch d.i.b. top for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
	GREEN[3/]						
6	302	360	417	474			
7	406	484	561	638			
8	525	625	725	825	924		
9	658	784	910	1,034	1,158	1,282	
10	806	961	1,114	1,267	1,418	1,570	1,720
11	968	1,154	1,338	1,521	1,704	1,885	2,066
12	1,145	1,364	1,582	1,798	2,014	2,229	2,443
13	1,335	1,591	1,845	2,098	2,349	2,600	2,849
14	1,540	1,834	2,128	2,419	2,709	2,998	3,286
15	1,758	2,095	2,429	2,762	3,093	3,423	3,752
16		2,372	2,750	3,127	3,502	3,875	4,247
17		2,665	3,090	3,514	3,935	4,355	4,773
18			3,449	3,922	4,392	4,861	5,327
19			3,827	4,352	4,874	5,393	5,911
20			4,224	4,803	5,379	5,952	6,523
	DRY[4/]						
6	164	195	227	259			
7	221	264	307	349			
8	287	342	398	453	508		
9	361	431	501	570	640	709	
10	443	529	615	700	785	870	955
11	533	637	740	843	946	1,048	1,150
12	632	755	877	999	1,121	1,242	1,363
13	739	882	1,025	1,168	1,310	1,452	1,593
14	853	1,019	1,185	1,350	1,514	1,678	1,841
15	976	1,166	1,355	1,544	1,732	1,919	2,106
16		1,323	1,537	1,751	1,964	2,176	2,388
17		1,489	1,730	1,971	2,210	2,450	2,688
18			1,934	2,203	2,471	2,738	3,005
19			2,149	2,448	2,746	3,043	3,339
20			2,375	2,705	3,035	3,363	3,690

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -0.65002 + 0.96146 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -0.96015 + 0.97497 \text{ Log}_{10} D^2Th.$

Table 16.--Predicted weight of wood excluding bark in main stem to 2-inch d.i.b. top for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet) [2/]						
	50	60	70	80	90	100	110
	Pounds						
GREEN [3/]							
6	263	315	367	419			
7	357	427	497	567			
8	464	556	647	738	829		
9	586	701	816	931	1,046	1,160	
10	721	863	1,005	1,146	1,287	1,428	1,568
11	870	1,041	1,212	1,383	1,553	1,723	1,893
12	1,033	1,236	1,439	1,642	1,844	2,045	2,247
13	1,209	1,448	1,685	1,922	2,159	2,395	2,631
14	1,400	1,675	1,950	2,224	2,498	2,772	3,045
15	1,604	1,919	2,234	2,548	2,862	3,175	3,488
16		2,180	2,537	2,894	3,251	3,606	3,961
17		2,456	2,859	3,262	3,663	4,064	4,464
18			3,200	3,651	4,100	4,549	4,997
19			3,560	4,061	4,561	5,060	5,559
20			3,939	4,493	5,046	5,599	6,150
DRY [4/]							
6	139	167	195	223			
7	190	228	266	304			
8	248	298	348	398	448		
9	314	378	441	504	568	631	
10	389	467	545	623	702	780	859
11	471	566	660	755	850	945	1,040
12	561	674	787	900	1,013	1,126	1,239
13	659	791	924	1,057	1,190	1,323	1,456
14	765	919	1,073	1,227	1,381	1,536	1,690
15	879	1,055	1,232	1,410	1,587	1,764	1,942
16		1,202	1,403	1,605	1,807	2,009	2,211
17		1,358	1,585	1,813	2,041	2,269	2,498
18			1,778	2,034	2,290	2,546	2,802
19			1,983	2,268	2,553	2,839	3,124
20			2,198	2,514	2,831	3,147	3,464

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -0.78784 + 0.98563 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -1.13120 + 1.00588 \text{ Log}_{10} D^2Th.$

Table 17.--Predicted weight of bark in main stem to 2-inch d.i.b. top for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
GREEN[3/]							
6	40	45	51	56			
7	49	57	63	70			
8	60	69	77	85	92		
9	71	82	91	101	110	118	
10	83	95	106	117	128	138	148
11	96	109	122	135	147	158	170
12	109	124	139	153	167	180	193
13	122	139	156	172	187	202	217
14	136	155	174	191	208	225	241
15	150	172	192	212	231	249	267
16		189	211	232	253	273	293
17		206	230	254	277	299	320
18			250	276	301	325	348
19			271	299	325	351	377
20			292	322	351	379	406
DRY[4/]							
6	25	29	32	35			
7	32	36	40	44			
8	38	44	49	54	58		
9	45	52	58	64	69	75	
10	53	60	67	74	80	87	93
11	60	69	77	85	92	100	107
12	69	78	87	96	105	113	121
13	77	88	98	108	117	127	136
14	86	98	109	120	131	141	151
15	94	108	120	132	144	156	167
16		118	132	145	158	171	183
17		129	144	159	173	186	199
18			156	172	187	202	217
19			169	186	203	219	234
20			182	200	218	235	252

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -0.77468 + 0.72855 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -0.93976 + 0.71954 \text{ Log}_{10} D^2Th.$

Table 18.--Predicted weight of crown material (branchwood, branchbark, and needles) in longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
GREEN[3/]							
6	46	56	67	78			
7	65	80	95	110			
8	88	108	128	149	170		
9	114	140	167	194	222	250	
10	145	178	212	246	281	317	353
11	180	221	263	305	349	393	437
12	219	269	319	371	424	478	532
13	262	322	383	445	508	572	637
14	310	380	452	526	601	676	753
15	362	444	528	614	702	790	880
16		514	611	711	812	914	1,018
17		589	701	815	930	1,048	1,167
18			797	927	1,058	1,192	1,327
19			901	1,047	1,196	1,347	1,499
20			1,011	1,175	1,342	1,512	1,683
DRY[4/]							
6	22	27	32	37			
7	31	38	45	53			
8	42	52	61	72	82		
9	55	67	80	94	107	121	
10	70	86	102	119	136	153	171
11	87	107	127	148	169	191	213
12	106	130	155	180	206	233	259
13	127	156	186	216	248	279	311
14	150	185	220	256	293	331	369
15	176	216	258	300	343	387	431
16		250	298	348	398	448	500
17		287	343	399	457	515	574
18			390	455	520	587	654
19			442	514	588	663	740
20			497	578	661	746	831

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}Y = -2.00999 + 1.12764 \text{ Log}_{10}D^2Th.$
[4/] $\text{Log}_{10}Y = -2.37618 + 1.14054 \text{ Log}_{10}D^2Th.$

Table 19.--Predicted weight of wood and bark in branches for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
	GREEN[3/]						
6	24	30	36	43			
7	35	44	54	63			
8	49	61	74	88	102		
9	65	82	100	118	137	156	
10	85	107	130	154	178	204	229
11	108	136	165	195	227	259	292
12	135	169	206	243	282	322	363
13	165	207	251	297	345	394	444
14	198	250	303	358	415	474	535
15	236	297	360	426	494	564	636
16		349	424	501	581	664	748
17		407	494	584	677	773	872
18			570	674	782	893	1,006
19			653	772	896	1,023	1,153
20			743	879	1,019	1,164	1,312
	DRY[4/]						
6	12	16	19	22			
7	18	23	28	33			
8	25	32	39	46	53		
9	34	43	52	61	71	81	
10	44	56	67	80	92	105	118
11	56	71	86	101	117	133	150
12	70	88	106	125	145	166	187
13	85	107	130	153	177	202	228
14	103	129	156	184	213	243	274
15	122	153	185	219	253	289	325
16		180	217	257	297	339	382
17		209	253	299	346	394	444
18			292	344	399	455	512
19			334	394	456	520	586
20			379	448	518	591	665

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}Y = -2.72222 + 1.25770 \text{ Log}_{10}D^2Th.$
[4/] $\text{Log}_{10}Y = -2.95713 + 1.24480 \text{ Log}_{10}D^2Th.$

Table 20.--Predicted weight of branchwood in longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
GREEN[3/]							
6	14	18	22	26			
7	21	27	33	39			
8	30	38	47	56	66		
9	41	52	64	77	90	104	
10	54	69	85	102	120	138	157
11	70	90	110	132	154	178	202
12	89	113	139	167	195	225	255
13	110	140	173	206	242	278	316
14	134	171	210	252	295	340	386
15	161	206	253	303	355	409	464
16		245	301	360	422	486	552
17		288	354	424	496	572	650
18			413	494	579	667	757
19			478	571	669	771	876
20			548	656	768	884	1,005
DRY[4/]							
6	7	9	11	13			
7	10	13	16	19			
8	15	19	23	28	33		
9	20	26	32	38	45	51	
10	27	34	42	51	59	68	77
11	35	44	55	65	76	88	100
12	44	56	69	82	96	111	126
13	54	69	85	102	119	137	156
14	66	85	104	124	145	167	190
15	80	102	125	149	175	201	229
16		121	148	178	208	239	272
17		142	175	209	244	281	320
18			203	243	285	328	372
19			235	281	329	379	430
20			270	322	377	434	493

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -3.22660 + 1.34140 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -3.51387 + 1.33673 \text{ Log}_{10} D^2Th.$

Table 21.--Predicted weight of branchbark in longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Pounds						
GREEN[3/]							
6	10	12	15	17			
7	14	17	20	23			
8	19	23	27	31	35		
9	24	30	35	40	46	51	
10	30	37	44	50	57	64	71
11	37	45	54	62	70	79	87
12	45	55	65	75	85	95	105
13	54	65	77	89	101	113	125
14	63	76	90	104	118	132	147
15	73	89	105	121	137	154	170
16		102	120	139	158	177	196
17		116	137	158	180	201	223
18			155	179	203	227	252
19			174	201	228	256	283
20			194	224	255	285	316
DRY[4/]							
6	6	7	8	10			
7	8	10	11	13			
8	11	13	15	18	20		
9	14	17	20	23	26	29	
10	17	21	25	29	32	36	40
11	21	26	30	35	40	44	49
12	25	31	37	42	48	54	59
13	30	37	43	50	57	64	70
14	35	43	51	59	67	75	83
15	41	50	59	68	77	86	96
16		57	68	78	89	99	110
17		65	77	89	101	113	125
18			87	101	114	128	141
19			98	113	128	143	159
20			109	126	143	160	177

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -2.49769 + 1.07628 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -2.72978 + 1.07216 \text{ Log}_{10} D^2Th.$

Table 22.--Predicted green volume of wood and bark in total tree for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Cubic feet						
WOOD[3/]							
6	4.1	5.0	5.8	6.7			
7	5.7	6.9	8.1	9.3			
8	7.5	9.1	10.7	12.3	13.9		
9	9.6	11.7	13.7	15.8	17.8	19.9	
10	12.0	14.5	17.1	19.7	22.2	24.8	27.5
11	14.7	17.8	20.9	24.0	27.2	30.3	33.5
12	17.6	21.3	25.1	28.8	32.6	36.4	40.3
13	20.8	25.2	29.6	34.1	38.6	43.1	47.6
14	24.3	29.4	34.6	39.8	45.1	50.3	55.6
15	28.1	34.0	40.0	46.0	52.1	58.2	64.3
16		39.0	45.8	52.7	59.6	66.6	73.6
17		44.3	52.0	59.9	67.7	75.7	83.6
18			58.7	67.5	76.4	85.3	94.3
19			65.7	75.6	85.5	95.5	105.6
20			73.2	84.2	95.3	106.4	117.6
DRY[4/]							
6	1.3	1.4	1.6	1.8			
7	1.6	1.9	2.1	2.4			
8	2.0	2.3	2.6	2.9	3.2		
9	2.4	2.8	3.2	3.5	3.9	4.2	
10	2.9	3.3	3.8	4.2	4.6	5.0	5.4
11	3.3	3.9	4.4	4.9	5.4	5.9	6.3
12	3.8	4.5	5.1	5.6	6.2	6.8	7.3
13	4.4	5.1	5.8	6.4	7.1	7.7	8.3
14	4.9	5.7	6.5	7.2	8.0	8.7	9.4
15	5.5	6.4	7.3	8.1	8.9	9.7	10.5
16		7.1	8.1	9.0	9.9	10.8	11.6
17		7.9	8.9	9.9	10.9	11.9	12.8
18			9.8	10.9	12.0	13.0	14.1
19			10.7	11.9	13.1	14.2	15.4
20			11.6	12.9	14.2	15.5	16.7

continued

Table 22.--Predicted green volume of wood and bark in total tree for longleaf pine trees 6 to 20 inches d.b.h.[1/] (continued)

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Cubic feet						
	WOOD AND BARK[5/]						
6	5.3	6.4	7.5	8.6			
7	7.3	8.8	10.2	11.7			
8	9.5	11.5	13.4	15.3	17.2		
9	12.1	14.5	17.0	19.4	21.8	24.3	
10	14.9	18.0	21.0	24.0	27.0	30.0	33.0
11	18.1	21.7	25.4	29.0	32.7	36.4	40.0
12	21.6	25.9	30.3	34.6	39.0	43.3	47.7
13	25.3	30.4	35.5	40.6	45.8	50.9	56.0
14	29.4	35.3	41.2	47.2	53.1	59.0	65.0
15	33.8	40.6	47.4	54.2	61.0	67.8	74.7
16		46.2	54.0	61.7	69.5	77.2	85.0
17		52.2	61.0	69.7	78.5	87.3	96.0
18			68.4	78.2	88.0	97.9	107.7
19			76.2	87.2	98.2	109.1	120.1
20			84.5	96.7	108.8	121.0	133.2

1/ Blocked-in area indicates range of data.
2/ Includes 1-foot stump allowance.
3/ $\text{Log}_{10}\ Y = -2.80224 + 1.04936\ \text{Log}_{10}\ D^2Th.$
4/ $\text{Log}_{10}\ Y = -2.54434 + 0.81138\ \text{Log}_{10}\ D^2Th.$
5/ $\text{Log}_{10}\ Y = -2.54553 + 1.00570\ \text{Log}_{10}\ D^2Th.$

Table 23.--Predicted green volume of wood and bark in main stem to 2-inch d.i.b. top for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Cubic feet						
	WOOD[3/]						
6	3.9	4.7	5.5	6.3			
7	5.3	6.4	7.5	8.6			
8	7.0	8.5	9.9	11.3	12.8		
9	8.9	10.7	12.6	14.4	16.2	18.1	
10	11.1	13.3	15.6	17.9	20.1	22.4	24.7
11	13.4	16.2	18.9	21.7	24.5	27.2	30.0
12	16.0	19.3	22.6	25.9	29.2	32.5	35.8
13	18.9	22.7	26.6	30.5	34.4	38.3	42.2
14	22.0	26.4	30.9	35.5	40.0	44.5	49.0
15	25.3	30.4	35.6	40.8	46.0	51.2	56.4
16		34.7	40.6	46.5	52.5	58.4	64.4
17		39.3	46.0	52.7	59.4	66.1	72.9
18			51.6	59.2	66.7	74.3	81.9
19			57.7	66.1	74.5	82.9	91.4
20			64.0	73.3	82.7	92.1	101.5
	BARK[4/]						
6	1.0	1.2	1.3	1.4			
7	1.3	1.5	1.6	1.8			
8	1.6	1.8	2.0	2.2	2.4		
9	1.8	2.1	2.3	2.6	2.8	3.0	
10	2.1	2.4	2.7	3.0	3.2	3.5	3.7
11	2.4	2.8	3.1	3.4	3.7	3.9	4.2
12	2.7	3.1	3.5	3.8	4.1	4.5	4.8
13	3.1	3.5	3.9	4.3	4.6	5.0	5.3
14	3.4	3.9	4.3	4.7	5.1	5.5	5.9
15	3.8	4.3	4.7	5.2	5.7	6.1	6.5
16		4.7	5.2	5.7	6.2	6.7	7.1
17		5.1	5.7	6.2	6.7	7.2	7.7
18			6.1	6.7	7.3	7.9	8.4
19			6.6	7.2	7.9	8.5	9.0
20			7.1	7.8	8.5	9.1	9.7

continued

Table 23.--Predicted green volume of wood and bark in main stem to 2-inch d.i.b. top for longleaf pine trees 6 to 20 inches d.b.h.[1/] (continued)

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Cubic feet						
	WOOD AND BARK[5/]						
6	4.9	5.9	6.8	7.8			
7	6.6	7.9	9.2	10.5			
8	8.6	10.3	11.9	13.6	15.2		
9	10.8	12.9	15.0	17.1	19.1	21.2	
10	13.3	15.8	18.4	21.0	23.5	26.0	28.6
11	16.0	19.1	22.2	25.2	28.3	31.3	34.4
12	18.9	22.6	26.2	29.9	33.5	37.1	40.7
13	22.1	26.4	30.6	34.9	39.1	43.3	47.5
14	25.5	30.5	35.4	40.3	45.2	50.0	54.9
15	29.2	34.8	40.5	46.1	51.7	57.2	62.8
16		39.5	45.9	52.2	58.6	64.9	71.2
17		44.4	51.6	58.8	65.9	73.0	80.1
18			57.7	65.7	73.6	81.5	89.5
19			64.1	72.9	81.8	90.6	99.4
20			70.8	80.6	90.3	100.1	109.8

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -2.72558 + 1.01904 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -2.25358 + 0.69804 \text{ Log}_{10} D^2Th.$
[5/] $\text{Log}_{10} Y = -2.47035 + 0.97145 \text{ Log}_{10} D^2Th.$

Table 24.--Predicted green volume of wood and bark in branches for longleaf pine trees 6 to 20 inches d.b.h.[1/]

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Cubic feet						
WOOD[3/]							
6	0.2	0.3	0.4	0.4			
7	.4	.5	.6	.7			
8	.5	.7	.8	.9	1.1		
9	.7	.9	1.1	1.3	1.5	1.7	
10	.9	1.2	1.4	1.7	2.0	2.3	2.6
11	1.2	1.5	1.8	2.2	2.5	2.9	3.3
12	1.5	1.9	2.3	2.7	3.2	3.6	4.1
13	1.8	2.3	2.8	3.4	3.9	4.5	5.1
14	2.2	2.8	3.4	4.1	4.7	5.4	6.2
15	2.6	3.3	4.1	4.9	5.7	6.5	7.4
16		4.0	4.8	5.8	6.7	7.7	8.7
17		4.6	5.7	6.7	7.9	9.0	10.2
18			6.6	7.8	9.1	10.5	11.8
19			7.6	9.0	10.5	12.0	13.6
20			8.6	10.3	12.0	13.8	15.6
BARK[4/]							
6	0.2	0.3	0.3	0.4			
7	.3	.4	.5	.5			
8	.4	.5	.6	.7	0.8		
9	.6	.7	.8	.9	1.1	1.2	
10	.7	.9	1.0	1.2	1.3	1.5	1.7
11	.9	1.1	1.2	1.4	1.6	1.8	2.0
12	1.0	1.3	1.5	1.7	2.0	2.2	2.4
13	1.2	1.5	1.8	2.1	2.3	2.6	2.9
14	1.5	1.8	2.1	2.4	2.7	3.1	3.4
15	1.7	2.1	2.4	2.8	3.2	3.6	3.9
16		2.4	2.8	3.2	3.6	4.1	4.5
17		2.7	3.2	3.7	4.1	4.6	5.1
18			3.6	4.1	4.7	5.2	5.8
19			4.0	4.6	5.3	5.9	6.5
20			4.5	5.2	5.9	6.6	7.3

continued

Table 24.--Predicted green volume of wood and bark in branches for longleaf pine trees 6 to 20 inches d.b.h.[1/] (continued)

D.b.h. (inches)	Total tree height (feet)[2/]						
	50	60	70	80	90	100	110
	Cubic feet						
	WOOD AND BARK[5/]						
6	0.5	0.6	0.7	0.8			
7	.7	.9	1.0	1.2			
8	1.0	1.2	1.4	1.7	1.9		
9	1.3	1.6	1.9	2.2	2.6	2.9	
10	1.6	2.0	2.5	2.9	3.3	3.8	4.2
11	2.1	2.6	3.1	3.6	4.2	4.8	5.4
12	2.5	3.2	3.8	4.5	5.2	5.9	6.6
13	3.1	3.9	4.6	5.5	6.3	7.1	8.0
14	3.7	4.6	5.6	6.5	7.5	8.5	9.6
15	4.4	5.4	6.6	7.7	8.9	10.1	11.3
16		6.4	7.7	9.0	10.4	11.8	13.2
17		7.4	8.9	10.4	12.0	13.7	15.3
18			10.2	12.0	13.8	15.7	17.6
19			11.6	13.7	15.8	17.9	20.1
20			13.2	15.5	17.8	20.3	22.7

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10} Y = -4.84899 + 1.30101 \text{ Log}_{10} D^2Th.$
[4/] $\text{Log}_{10} Y = -4.10690 + 1.07007 \text{ Log}_{10} D^2Th.$
[5/] $\text{Log}_{10} Y = -4.26121 + 1.20985 \text{ Log}_{10} D^2Th.$

Taras, Michael A., and Alexander Clark III

1976. Aboveground biomass of longleaf pine in a natural sawtimber stand in southern Alabama. USDA For. Serv. Res. Pap. SE-162. 32 p. Southeast. For. Exp. Stn., Asheville, N.C.

Longleaf pine trees 6 to 18 inches d.b.h. were selected from a natural, uneven-aged sawtimber stand in southern Alabama to determine weight and volume of aboveground biomass. On the average, 85 percent of the dry weight of the total tree was wood, 11 percent was bark, and 4 percent was needles. The average tree sampled had 88 percent of its wood in the stem and 12 percent in the crown. Trends in biomass proportions are discussed. Specific gravity, moisture content, and green weight per cubic foot are presented for the total tree and its components. Tables developed with regression equations predict weight and cubic foot volume of the total tree and its components by d.b.h. and total height classes.

Keywords: Pinus palustris Mill., weight, volume, prediction equations, component proportions, biomass.

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Keywords: Pinus palustris Mill., weight, volume, prediction equations, component proportions, biomass.

The Forest Service, U. S. Department of Agriculture, is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives—as directed by Congress—to provide increasingly greater service to a growing Nation.

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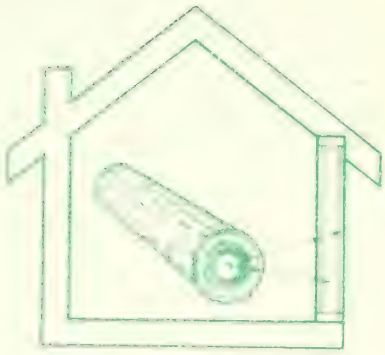
13.78 SE-163

USDA Forest Service Research Paper SE-163 January 1977



COM-PLY 3 REPORT

PLYWOOD COMPOSITE PANELS FOR FLOORS AND ROOFS: SUMMARY REPORT

AMERICAN PLYWOOD ASSOCIATION

U.S. DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

NATIONAL FOREST SYSTEM COOPERATIVE FORESTRY FORESTRY RESEARCH

COOPERATIVE RESEARCH

PLYWOOD COMPOSITE PANELS FOR FLOORS AND ROOFS: SUMMARY REPORT

edited by

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Cooperative Research by

U.S. Department of Agriculture, Forest Service
Southeastern Forest Experiment Station

U.S. Department of Housing and Urban Development
Division of Energy, Building Technology
and Standards

and

American Plywood Association
Technical Services Division

PREFACE

This is a summary of "Plywood Composite Panels for Floors and Roofs," American Plywood Association Report 135. The original report contains over 300 pages of laboratory research results. Readers interested in more comprehensive details, tables, graphs and design formulas than contained in this summary report should refer to APA Report 135.

The present report is one of a series on the possibilities of producing house framing and structural panels with particleboard cores and veneer facings. These composite materials were designed to be used interchangeably with conventional plywood in homes. Research on structural panels is presently limited to floor and roof panels but will be extended to include other types of composite plywood panels.

In 1973, the home-building industry faced a shortage of lumber and plywood, and consequent rising prices. Both industry and government recognized that this situation was not a temporary problem, and that long-range plans for better using the Nation's available forest resources would be necessary to solve the problem.

The USDA Forest Service, American Plywood Association, and the U.S. Department of Housing and Urban Development accelerated cooperative research on ways to utilize the whole tree. They concentrated on composite wood products made with particleboard and veneer as a way of using not only more of the tree stem, but also using less desirable trees and a greater variety of tree species than would conventional wood products. The particleboard which comprises a large portion of the composite panel is made from milled wood that comes from forest residues, mill residues, or low-quality timber. Thus, such composites could greatly increase the amount of plywood available for residential construction, one of our major uses of wood, without eroding the Nation's timber supply.

Research on composite plywood panels was performed by the American Plywood Association, which designed and tested composite panel products and incorporated them in demonstration houses.

Included in this series will be reports on structural properties, durability, dimensional stability, strength, and stiffness of composite studs. Other reports will describe the overall project, report results of building demonstration houses, compare the strength of composite and solid wood studs, suggest performance standards for composite studs, and provide construction details on houses incorporating such studs. Still others will explore the economic feasibility of manufacturing composite studs and panels and estimate the amount and quality of veneer available from southern pines. These reports, called the COM-PLY series, will be available from the Southeastern Forest Experiment Station and the U.S. Department of Housing and Urban Development.

ACKNOWLEDGMENT

The Forestry Sciences Laboratory, Wood Products Research Unit, acknowledges the valuable assistance and guidance of:

Orville G. Lee, A.I.A.
Howard C. Hilbrand, P.E.
U.S. Department of Housing and Urban Development

David R. Countryman, P.E.
American Plywood Association

Abstract.--The composite panel is a new type of plywood. It has a structural core of reconstituted wood, with veneer faces. Tests have established a means of evaluating quality of core and gluelines during production. Other tests established its ability to withstand in-service loads, both concentrated and impact. Further testing developed means of predicting performance of a composite panel based on the known properties of its constituent parts. Two demonstration houses, one on the East and one on the West Coast, illustrated the handling qualities of the composite panel, and established that such panels could be used interchangeably with regular plywood for certain uses. Several producers have expressed interest in manufacturing the panel, and one mill has already been built specifically for this purpose. Although the major questions have been answered with respect to floor and roof-sheathing applications, additional work will be required to evaluate composite panels for use in other panel applications.

KEYWORDS: Particleboard, fiberboard, waferboard, flakeboard, sheathing, roof sheathing, subfloor, single floor, subfloor-underlayment, underlayment.

CONTENTS

Introduction 1

Part 1 — Durability 3

Abstract 3

Development of Test. 3

Types of Tests 4

Test Chosen. 4

Further Development 4

Part 2 — In-Use Performance Requirements 5

Objectives 5

Procedure 5

Required Loads 5

Development of Tests 6

Composites Tested 7

Part 3 — Panel Properties and Design 8

Abstract 8

Scope and Approach 8

Comparison of Plywood and Composite Panels 9

Design Methods for Bending and Concentrated Load Deflection 9

Part 4 — Tables Comparing Bending Strength and Stiffness of Composite Panels and Plywood 10

Part 5 — Demonstration Houses 11

Project Summary 13

INTRODUCTION

by David R. Countryman, P.E., Project Leader
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In response to the need to develop more effective use of our forest resources, the American Plywood Association undertook a study of composite panels intended to augment the supply of plywood.

The composite panel consists of a structural core of reconstituted wood, overlaid with a veneer face and back. Boards used for cores in composite panels include those referred to in the trade as particleboard, flakeboard, and the like.

The Plywood Association undertook this investigation after strong interest had been expressed by a number of member mills. Substantial assistance was received from the Forest Service and the Department of Housing and Urban Development.

Study Objectives

The primary objective of the study was to investigate the properties of a composite panel, relative to its use for flooring and roof sheathing in light-frame construction. The study was conducted on a representative range of commercially produced boards, rather than on laboratory-tailored specimens, so as to obtain performance similar to what might be anticipated in practice.

The four main aspects of the study were durability, in-use performance requirements, flexural design, and dimensional stability.

Durability

A primary requirement of any building panel is that it be durable in its environment. It must not come apart, either in the glue bond or in the board material itself, either under the effect of weather during construction, or of moisture, humidity, and temperature during the rest of the life of the building. The aim was to develop a test method which would determine whether an individual panel would meet this requirement, and which would also be quick enough to be suitable for checking quality during subsequent production.

In-Use Performance Requirements

A building panel has many in-use requirements, such as nail-holding, racking strength, resistance to fire, and acoustical properties. The most important one is the ability to withstand concentrated loads—both static and impact.

The life of a building includes the phase of construction, which is often the most severe test of panel performance. Where construction loads appeared to be the most severe condition, panels were tested wet as well as dry. Similarily, where occupancy loads governed, as in a finish floor, panels were tested not only dry but also after having been wet and then redried.

Performance requirements were developed, therefore, for three applications—roof sheathing, subflooring, and single-layer floors. Spacings of support framing were 16" and 24".

Design

It was also felt desirable to be able to calculate the performance of the composite panel based on the known properties of its constituent parts, that is, the veneer faces and the core.

Dimensional Stability

A major requirement for panels in the proposed applications is the physical property of dimensional stability, or resistance to linear expansion. Such expansion of floor and roof sheathing can produce unacceptable buckling of the panels, and even a small amount of swelling in a single-layer floor is enough to make it buckle so as to be unsuitable for installation of resilient finish flooring.

Limitations

This extensive series of test programs established the feasibility of manufacturing and use of composite panels. There is, however, considerable work yet to be done on a number of aspects of composite-panel development. These tests were restricted to construction panels only, and then only for roof sheathing, floor sheathing, and single floors. Furthermore, no studies were made as to manufacturing specifications, either for the board or for the composite panel itself. Nor did APA work include any exploration of production methods or economics of manufacture. (Gerald Koenigshof of the U.S. Forest Service, working with a consultant, did conduct a rather extensive study of economics.)

Demonstration Houses

As a demonstration of the suitability of composite panels for the various applications, two houses were built using these materials for single-floor, roof sheathing, and, in one case, exterior siding. (Use of panels for exterior siding was not initially planned, but the opportunity presented itself in the course of the investigation, resulting in a substantial level of interest.) The demonstration houses served as vehicles for introducing the composite panel to many potential manufacturers, code officials, and the building community. At the same time, these demonstration houses showed that composite panels could, in fact, be used interchangeably with regular plywood for sheathing.

Industry Action

The composite panel study has already led to significant action. During the course of the investigation, papers based on the project were delivered at the eighth and ninth Particleboard Symposiums at Washington State University; four papers were delivered by APA staff before the national meetings of the Forest Products Research Society; and papers were presented to the plywood industry at its 1975 annual meetings.

Tours of the demonstration house in Vancouver were attended by several hundred from the APA and FPRS meetings, as well as meetings of BOCA and ICBO. The eastern house was visited by numerous representatives of federal agencies, particularly HUD and the Forest Service, as well as representatives of the building industry, including members of the NAHB research staff and of the press. The Department of Housing and Urban Development made movies at various stages during its construction.

Several Association member mills have expressed interest in possible production of a composite panel, and one mill has been built specifically for this production. As more products become available an Association Product Standard will be prepared for composite panels, to be reviewed by the APA Special Products Committee.

Future Work Required

Finally, although the major questions have been answered with respect to floor and roof sheathing applications, it has become apparent that additional work will be required to permit composite panels to be used in other plywood applications. Additional information on dimensional stability is needed, not only for sheathing, but particularly for exterior siding. Development of information on fully exterior durability is required. Other engineered applications such as concrete forms will also require further investigation.

However, it is believed that the present study was properly directed in its initial objective of investigating protected sheathing applications, and that the results will be sufficient to get a good start into substantial production of the composite panel.

PART 1 – DURABILITY

by Carl Erb, APA Quality Laboratories Department
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Abstract

A tentative test method has been developed for quality control of composite-panel production. The purpose of such a test is to ascertain, in a short test period, the ultimate outdoor durability of the panel. The method tentatively adopted requires a three-day period, and correlates adequately with one-year exposure on an outdoor exposure fence. This method will continue to be checked against exposure-fence results, and modified accordingly as required.

Development of Test

Three- and five-ply composite panels were made using nine different board types (five phenolic and four urea), two veneer species (southern pine and Douglas fir), and three glue types (exterior, extended-resin interior, and hot-press-protein interior). Three-ply plywood panels were also glued as controls. Gluing conditions were designed to produce well-bonded, as well as poorly bonded, material for evaluation of test method. A total of 520 laboratory panels were manufactured.

Test specimens were cut to provide matching material for twelve different types of laboratory tests. In addition, 2080 specimens were mounted on an outdoor exposure fence, including 1040 "permanent" specimens to be examined periodically over the next five years, and 1040 specimens which will be removed and returned to the laboratory following various periods of exposure and tested to determine the effects of exposure on bond quality. See Figure 1 for a picture of a part of the exposure fence.

FIGURE 1 EXPOSURE FENCE AT TACOMA, WASHINGTON showing method of mounting specimens for exposure testing. The author in foreground discussing testing with Howard Hilbrand of HUD.

Of the ten tests conducted on phenolic composite panels, a cyclic-delamination test provided the best correlation between outdoor exposure and short-term laboratory test results. Tentative performance criteria have been established which will be subject to review as additional data become available from examination of outdoor exposure specimens.

Types of Tests

Existing test procedures for both plywood and reconstituted board products were investigated, and none was found directly applicable to composite panels. Existing test procedures for board products included only one which actually reflected long-term durability, and this method was found to be too time-consuming and cumbersome for routine quality testing. Although shear testing is the most feasible method for use with conventional plywood, it did not prove satisfactory with the board cores, since the majority of failures took place in the core, regardless of quality of bond between core and face veneers. Cyclic-delamination analysis was the next criterion investigated, and it seems to give satisfactory results.

Test Chosen

The test procedure chosen involves six cycles of vacuum-soak and oven-dry within a three-day period. See Figure 2 for a photo of the vacuum-soak vessel. Total continuous visible delamination of 1/4" or more in depth and 1" in length in the veneer-to-veneer or veneer-to-board glueline, or within the board itself, is considered a failure. The quality testing method is being used for current production of composite panels.

Further Development

Experience to date indicates that phenolic resin will be required both for the core-board and for the core-to-veneer glueline, if durability of the composite is to be comparable to plywood with exterior glue. Other combinations of materials, such as urea-board cores and protein adhesives, may perform adequately in less demanding applications.

FIGURE 2 VACUUM-SOAK VESSELS, one in operation with the second being loaded. Specimens shown are 2" by 5"; those in test chosen are 1" by 5".

PART 2 – IN-USE PERFORMANCE REQUIREMENTS

by W. A. Baker, P.E., M. R. O'Halloran, Ph. D.,
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Technical Services Division

Objectives

There were two objectives for this portion of the study. Both were concerned with in-use performance of panels for roof sheathing, subflooring, and subfloor-underlayment combination. The first objective was to develop tests and acceptance criteria to define actual in-use requirements. The second was to test actual composite panels, using these tests and criteria, to establish their adequacy for the three uses noted.

Procedure

Development of the performance tests and acceptance criteria generally followed four steps. First, actual service loads and loads required by various codes were determined, in an extensive survey. Second, test procedures were developed based on the loads found in the survey. Third, a representative sampling of plywood was tested using these procedures, primarily to determine its behavior with respect to stiffness. Fourth, levels of performance were determined which would be deemed adequate for results in these tests.

Load requirements were developed from the actual loads and code requirements determined above. Required stiffness was based on the performance of plywood, which has a long record of consumer acceptance. Actual performance of composite panels was then measured using the tests and criteria developed. It was found that composite panels could be made which could be substituted for plywood of the same thickness.

Required Loads

The study on required loads included investigation of code "requirements," both in the United States and foreign countries. It also covered a field study of actual loads, both those applied during construction and during the service life of the structure. These actual service loads were found to be largely either concentrated static loads or impact loads. The heaviest concentrated static service loads on floors were found to be those from grand pianos, freezers, and hot-water heaters. Heaviest loads on roofs were those from equipment used to apply tar-and-gravel roofing. Figure 3 shows a roofing-felt layer.

The most severe impact loads which could normally be expected in service are those caused by people walking or jumping. Little data, however, was available on either condition. A test program was therefore developed.

FIGURE 3 ROOFING-FELT LAYER

Development of Tests

Development of concentrated-load tests was relatively straightforward. It involved approximating actual use conditions. Points requiring standardization were specimen width and loading-disc size. Figure 4 shows the loading and deflection-measuring apparatus.

Development of impact tests was considerably more involved. It was first necessary to determine, by testing, the actual effect of people jumping onto the panel surface. It was then necessary to develop how to approximate that effect in a laboratory. It was eventually determined that use of a standard leather "sandbag," carrying 30 lbs of lead shot, produced results best suited to evaluate service conditions. Figure 5 shows one of the "people jumps" involved in the developmental tests.

FIGURE 4 LOADING AND DEFLECTION-MEASURING APPARATUS

FIGURE 5 JUMPING TO THE FLOOR FROM A HEIGHT OF 36"

One standard "impact" test evaluated is known as the "spear" test. The spear is illustrated in Figure 6, as well as the shotbag. It is a metal rod with a 2-inch-diameter ball on the end, weighing approximately 18 lbs. This test was eventually discarded because the type of impact it causes is uncommon in service. Also, if such an impact occurred, almost any panel would be "punctured," but such punctures are easily repaired. Panel performance under such a loading, therefore, would not determine the suitability of the panel for service.

Representative plywood samples were obtained in two different series, from 46 different mills. They were tested under both concentrated static and impact loads, and their deflection performance was considered in developing criteria of acceptance for composite panels.

The performance of plywood was used as the basis of performance criteria only for deflection. It was chosen because it is essentially the only valid measure of consumer acceptance. Since plywood has been widely available for a number of years, and in many thicknesses, levels of performance acceptable to the public have been relatively well established. In one case, both "acceptable" and "preferred" levels were developed for these tests.

Composites Tested

Actual composite panels were tested. Three different thicknesses, with two different types of core board, were included. One of the boards had oriented strands, while the other had random orientation. Results of some 400 concentrated static load tests and 121 impact tests indicate performance and material variability similar to plywood. All indicators pointed to acceptability of composite panels for roof sheathing, subfloor, and single floor.

FIGURE 6 **IMPACT TESTING. Shotbag ready to drop. "Spear" is also shown, hanging at left of frame.**

PART 3 – PANEL PROPERTIES AND DESIGN

by D. A. Matteson, P. W. Post, and G. A. Ziegler, Ph. D.
Product Research Department
Technical Services Division

Abstract

Major properties for composite panels were compared with matching plywood panels. These properties included bending strength and stiffness, both along and across the panel; strength and stiffness under concentrated edge loads; and swelling across the panel width. Design methods were confirmed, by which bending strength and stiffness of composite panels can be calculated, except for the parallel bending strength of thick composites. Empirical equations were developed for deflection of unsupported panel edges under concentrated load at midspan. These equations reasonably predict deflections for the 16- and 24-inch spans tested.

Scope and Approach

Eleven hundred individual tests were performed on specimens of large size, including 35 plywood panels, 35 matching composite panels, and the constituent layers of the panels, tested individually before they were glued up. These tests were the basis for comparison of plywood and composite properties, as well as for development of design methods for bending and concentrated loads. A bending test is shown in Figure 7, and a tension test in Figure 8.

Seven different panel constructions were fabricated in the laboratory, including six panel thicknesses from 3/8 to 3/4 inch. Panels were tested in pairs, with a composite matched to a plywood panel. Each pair of panels was of equal thickness, with matched faces and matched back plies. In each pair, one panel had veneer inner plies, while the other had all inner plies replaced by one of six commercial boards.

FIGURE 7 BENDING TEST

FIGURE 8 TENSION TEST

Comparison of Plywood and Composite Panels

Composite-panel strength and stiffness parallel to face grain were comparable to plywood panels with all-Group-1 plies. Strength and stiffness in the cross-panel direction were about half the values for plywood having all-Group-1 plies, or approximately equal to plywood with Group-4 inner plies.

Strength under concentrated edge loading was generally comparable to plywood. Composite panels deflected less than plywood panels—from 6 to 13% less, depending upon construction.

See Figure 9 for a photo of the cross-panel dimensional-stability test. The cross-panel dimensional change of composites ranged from 1/5 greater to 13 times greater than plywood, after soaking. The composite with grain direction of the particles oriented across the panel was comparable to plywood. Two non-oriented flake boards, although less stable than plywood, were significantly more stable than the non-oriented cores with smaller particle size. Additional testing has been scheduled to determine the degree of dimensional stability actually required for various applications.

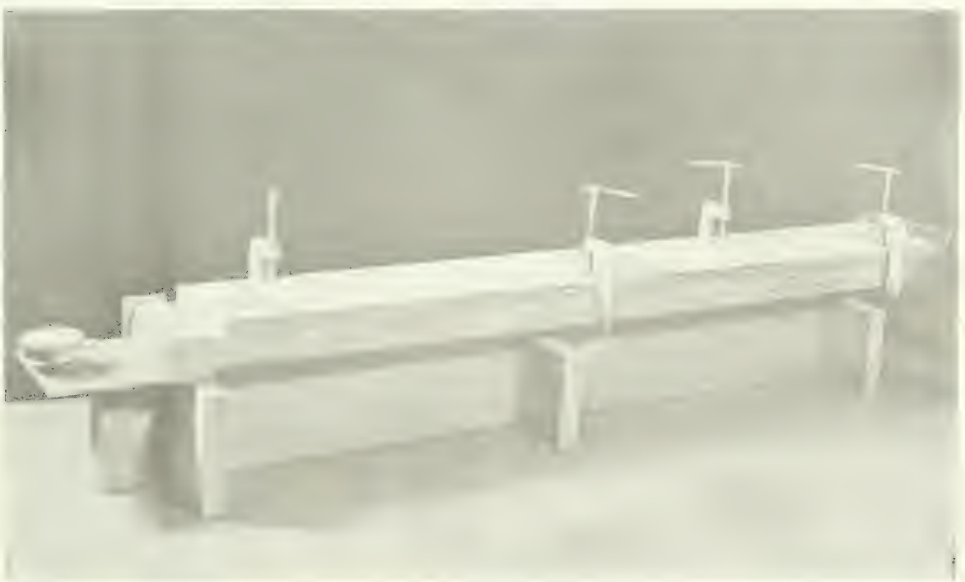
Design Methods for Bending and Concentrated-Load Deflection

Bending *stiffness,* both parallel and perpendicular to panel length, can be calculated from the properties of the constituent layers making up the panel. Bending *strength* perpendicular to the panel length can also be so calculated. *Parallel* bending strength, however, could not be calculated using these methods, due to interactions of the layers, which theory did not predict.

Parallel bending strength can be predicted, however, from the strength of a three-layer plywood panel of equal thickness, if strength and stiffness of the inner layers of both panels are known. Results indicated that 5-layer plywood panels were stronger than predicted by theory. Estimates of composite strength from such 5-layer panels, therefore, were too high.

A simple equation adequately predicted deflection under concentrated load for the span and support conditions tested. Values of parallel bending stiffness must be known to use this equation.

FIGURE 9 SETUP FOR TESTING CROSS-PANEL DIMENSIONAL STABILITY



PART 4 – TABLES COMPARING BENDING STRENGTH AND STIFFNESS OF COMPOSITE PANELS AND PLYWOOD

by D. A. Matteson and Paul Post
Product Research Department
Technical Services Division

Tables have been prepared to allow comparison of composite panels with average all-Group-1 plywood for *Bending Stiffness,* both parallel and perpendicular to face grain, and for *Bending Strength,* parallel (3-layer plywood) and perpendicular (3- and 5-layer) to face grain.

These tables also allow comparison of composite panels to *near-minimum* plywood panels, for stiffness and strength perpendicular to face grain. The tables cover composite panels with many combinations of thickness, construction, and coreboard properties. They should be useful to manufacturers wishing to compare properties of proposed composites to those of familiar plywood panels.

(Note: Readers interested in these tables should refer to American Plywood Association Report 135.)

PART 5 – DEMONSTRATION HOUSES

by Bruce Lyons, P.E., Manager
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Technical Services Division

Two demonstration houses have been built with composite panels--one on the East Coast and one in the West. The western house used composite panels for single-floor, single-wall siding, and roof sheathing. Although not a formal part of the project, the siding panel was included because of mill interest. The eastern house has single-floor and roof sheathing of composites. Figure 10 shows installation of flooring in the western house, while Figure 11 shows roofing being placed in the eastern house.

For both demonstration houses, roof sheathing was 7/16-inch thick, used over supports 24 inches on center, without Plyclips or other edge support. The single-floor for the western house was 5/8-inch tongue-and-groove, on supports 16 inches on center. Single-floor panels for the eastern house were 3/4-inch tongue-and-groove Underlayment, applied over joists at varying spacings up to 24 inches.

The siding panel, used only on the western house and not an official part of the project, was 5/8-inch thick, with rough-sawn surface and a reverse-board-and-batten pattern, with grooves spaced 12 inches on center.

FIGURE 10 LAYING COMPOSITE SINGLE-LAYER FLOOR PANELS, WESTERN DEMONSTRATION HOUSE

Three major tours of the western demonstration house took place in June and July, 1975. In addition, many unofficial tours of the facility were conducted for various wood-products-company officials, builders, and news-service representatives. Throughout the construction process, application of composite materials was monitored by APA staff members, representatives of the Forest Service, and officials of the Portland office of HUD.

The first major tour of the facility took place during the annual meeting of the Forest Products Research Society. Well over 100 wood-product scientists viewed the completed house prior to application of interior gypsum wall surfaces. A half-day session at the FPRS meeting was devoted to the composite panel.

The next major tour occurred during the annual meeting of the American Plywood Association, where again over 100 people toured the house. The majority of these people were representatives of plywood manufacturers.

The third large tour was conducted during the annual meeting of the Building Officials and Code Administrators International. This tour provided an opportunity for building officials to inspect the use of composite materials in residential construction.

The eastern demonstration house was purposely located near Washington, D.C. to permit first-hand observation of the construction process. During its construction, the Department of Housing and Urban Development made movies at various stages. In addition, several tours of the unit took place, including individuals representing HUD, the Forest Service, and members of the press. Representatives of the building industry, including members of the NAHB research staff, also observed the unit while the panels were still visible.

The composite panels used in the demonstration houses went into place easily, causing no problems. From a construction standpoint, such panels could be used interchangeably with regular plywood panels.

FIGURE 11 NAILING COMPOSITE ROOF SHEATHING, EASTERN DEMONSTRATION HOUSE

PROJECT SUMMARY

The objectives of the project have been generally achieved, and in many respects surpassed.

An accelerated test for durability of bond was developed and correlated with one-year outdoor exposure. The test evaluates both the core and the glue bond, and can be used to appraise composites made with various cores and resins. It is being used for quality testing of current production. Trial panels have been tested for at least seven member mills. Results have been instrumental in securing model-code acceptance for the first producing mill.

Structural performance requirements were developed for panels as used. Point loads, both static and impact, were considered. Magnitude of expected loads was determined from a survey, and required stiffness from the performance of plywood. From these requirements were developed test methods and criteria which will permit meaningful evaluation of any composite panels that may be produced for use as floor or roof sheathing.

Bending-strength properties of the composite were appraised. Methods were developed for calculating stiffness and strength of composites. Conventional bending theory, using properties of the individual layers, can be used with reasonable accuracy to calculate performance of composites under uniform bending loads, except for strength of thicker panels along the grain. Additional testing is being undertaken on this aspect. Concentrated-load deflection can also be estimated for a composite panel for typical roof-sheathing and subflooring applications.

To assist potential manufacturers, tables were developed that show bending properties compared with plywood, for composites made with cores having a common range of properties.

Linear expansion of composite panels was found to range from substantially equal to plywood for a cross-oriented core, up to much greater than plywood for other cores. Linear expansion is regarded as a measure of buckling tendency in typical applications. This one factor is considered to be at present the primary one which must be controlled, if it is not to limit composite sheathing and underlayment applications.

Two demonstration houses were site-built using composites. Handling and appearance were virtually identical with plywood.

Additional work will be required to validate applicability of panels with binders and adhesives other than phenol formaldehyde. Further work is also required on dimensional stability, and on other applications of composites, such as siding and concrete forming.

Carney, J. M., ed.
1977. Plywood composite panels for floors and roofs: Summary Report. USDA For. Serv. Res. Pap. SE-163, COM-PLY Rep. 3, 13 p. Southeast. For. Exp. Stn., Asheville, N. C., and U. S. Dep. Housing and Urban Develop., Washington, D. C.

The composite panel, a new type of plywood, has a structural core of reconstituted wood with veneer faces. Tests have established a means of evaluating quality of core and gluelines during production. Other tests established its ability to withstand in-service loads, both concentrated and impact. Further testing developed means of predicting performance of a composite panel on the basis of the known properties of its constituent parts. Two demonstration houses illustrated the handling qualities of the composite panel and established that such panels could be used interchangeably with regular plywood for certain uses.

KEYWORDS: Particleboard, fiberboard, waferboard, flakeboard, sheathing, roof sheathing, subfloor, single floor, subfloor-underlayment, underlayment.

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S. 7R:SE-164

USDA Forest Service Research Paper SE-164 October 1977

Precommercial Thinning of Naturally Seeded Slash Pine Increases Volume and Monetary Returns

by

Earle P. Jones Jr.

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U.S. Department of Agriculture - Forest Service
Southeastern Forest Experiment Station
Asheville, North Carolina

Precommercial Thinning of Naturally Seeded Slash Pine Increases Volume and Monetary Returns

by

Earle P. Jones, Jr., Principal Silviculturist

Macon, Georgia

Abstract.--A naturally seeded slash pine (Pinus elliottii Engelm. var. elliottii) stand, having up to 50,000 stems per acre, was precommercially thinned at age 3. Two thinning methods left single trees spaced 10 by 10 feet, and clumps of 6 to 8 trees spaced 10 by 10 feet, compared with the unthinned original stand. At age 23, the single-tree plots averaged 28 cords per acre of merchantable wood and the clump plots 19 cords. Unthinned plots yielded less than 5 cords, which were mostly inaccessible because of numerous, submerchantable stems. Such gains in commercial volumes can justify a sizable investment in precommercial thinning. Thinning by age 5 to less than 1,500 trees per acre is recommended. Diameter and height growth were inversely related to stand density. Heights at age 23 increased about 4 feet for each 1,000-tree decrease in stocking. When evaluating or comparing slash pine site indexes over a very broad range of densities, adjustments for trees per acre may be needed. Density effects are less important when the differences between stands are no more than 1,200 trees per acre, as would normally occur in managed stands.

Keywords: Precommercial thinning, Pinus elliottii, naturally seeded stands.

Precommercial thinning seems unattractive to many foresters because it destroys established trees and has no immediate monetary return. The research reported here, however, indicates that precommercial thinning can pay handsome dividends. A natural stand of slash pine (Pinus elliottii Engelm. var. elliottii) on the Holt Walton Experimental Forest in south central Georgia was thinned at age 3. Height, diameter, and volume responses to thinning were observed through age 23. Results illustrate the depressing effect high stocking densities have on individual tree growth.

METHODS

Two farm fields divided by a stream were left untended after the fall crop harvest of 1947. That year a bumper crop of slash pine seeds was produced. Mature, sawtimber-sized slash pines nearby cast an abundance of seed across the two fields. In 1951, the area was selected for this precommercial thinning study when seedlings were 3 years old. Initial inventories revealed some milacres containing the equivalent of 50,000 stems per acre.

Soil on the study site is Gilead loamy sand. Most of the area is level, but parts have 5 to 12 percent slopes. Steeper slopes had severe sheet erosion.

The study was arranged in a split-plot design to recognize the dissimilarity between fields. There were two randomized complete blocks within each field. Treatment plots were approximately 1/4 acre, and treatments were (fig. 1):

Single tree.--Stocking was reduced to single trees spaced approximately 10 by 10 feet apart.

Clump.--Stocking was reduced to clumps of 6 to 8 stems each, with clumps spaced approximately 10 by 10 feet apart, center to center.

Check.--Stocking was left as it existed, unthinned.

Figure 1.--Study plots immediately after precommercial thinning at age 3. Treatments are (fore- to background): clump, single-tree, and unthinned.

The method used to precommercially thin this area in 1951 was not unusual for that time. A two-wheel "buggy saw" with a belt-driven circular saw blade cut 10-foot-wide swaths across the plots. For the clump treatment, additional cutting left small clumps of about 6 to 8 trees at 10-foot intervals within the narrow strip of trees. The single-tree treatment was accomplished by additional thinning with an ax or brush hook to remove all but the single best tree in each clump. The check treatment was left untouched.

Diameters and heights were measured at intervals throughout the study. Through age 8, sampling was restricted to dominant and codominant trees which represented the potential crop trees, the trees most likely to survive to the end of the study. After age 8, the diameters of all plot trees were measured, but height measurements still were confined to dominants and codominants.

RESULTS

MORTALITY

Mortality throughout the study was largely a result of competition and was greatest on the check plots. One period of severe insect attack caused heavy losses in portions of some plots. Residual densities after thinning at age 3 averaged about 435 trees per acre for the single-tree treatment and 3,000 for the clump. Density on the unthinned check probably averaged over 20,000 stems per acre, although the figure is not precisely stated in the record. Twenty years after thinning, surviving trees per acre averaged 336 on the single-tree plots; 1,298 on the clump plots; and 3,978 on the check plots (table 1). Corresponding mortality rates approximated 23, 57, and 80 percent for the single-tree, clump and check plots. Mortality on the check plots was high throughout the 20-year period, being 30 percent from age 17 to 23, compared to 9 and 10 percent on the single and clump plots.

DIAMETER GROWTH

Five years after thinning it was noted that precommercial thinning had a significant effect on the diameter growth of dominant and codominant trees; the average diameter of single-tree plots was 0.9 inch larger than the average on the check plots (fig. 2). Ten years after thinning, single-tree plots averaged 0.9 inch larger than the clump treatment, and 2.4 inches larger than the check. Diameter differences continued to increase. Twenty years after thinning, diameters of dominants and codominants averaged 8.1 on the single-tree plots, 6.6 on the clump plots, and 4.5 on the check plots.

At age 17 (Collins 1967) and age 23, the inverse relationship between diameter and density of stocking was curvilinear. A least-squares regression (fig. 3) indicates that densities below 1,500 trees per acre provide the greatest increase in the average diameter of dominants and codominants. Each 100-tree reduction in stocking below the 1,500-tree level increased the mean diameter by 0.32 inch; for a similar stocking reduction above the 1,500-tree level the mean diameter increased by only 0.05 inch.

At age 23, diameters of all slash pines were measured on all plots. All trees in the single-tree treatment had diameters large enough for pulpwood (4.6 inches and larger), compared to 43 percent in the clump treatment, and only 8 percent in the check (table 2). Also, the average diameter for all trees on the single-tree treatment was 2.8 times larger than the check, and the clump treatment was 1.6 times larger than the check (table 1).

Table 1.--Number of trees, average diameter and height, 50-year site index, and volume production on individual treatment plots at age 23, 20 years after treatment

Field	Block	Trees per acre		Diameter at breast height[2]	Total height[3]	Site index[4]	Merchantable[1] volume per acre
		All	Merchantable[1]				
		Number		Inches	Feet		Cords
SINGLE-TREE							
I	1	401	401	7.8	56.2	78	37.54
I	2	331	331	7.7	56.1	78	30.86
II	3	331	331	7.3	51.8	72	22.46
II	4	279	279	7.3	53.0	74	20.23
Mean		336	336	7.5	54.3	76	27.77
CLUMP							
I	1	610	401	5.5	53.1	74	24.69
I	2	627	436	5.6	54.4	76	28.57
II	3	1,830	418	3.4	46.3	64	13.36
II	4	2,126	296	3.0	40.2	56	8.61
Mean		1,298	388	4.4	48.5	68	18.81
UNTHINNED							
I	1	3,415	192	2.8	39.8	55	4.49
I	2	2,128	508	3.6	46.6	65	13.40
II	3	5,802	17	2.1	33.9	47	.28
II	4	4,565	52	2.4	34.0	47	.81
Mean		3,978	192	2.7	38.6	54	4.74

[1] Trees 4.6 inches d.b.h. and above.
[2] Includes all crown classes.
[3] Dominant and codominant trees only.
[4] 50-year index age.

HEIGHT GROWTH

For the first 5 years after thinning, average height of dominants and codominants of the thinned treatments lagged behind the check, but differences were nonsignificant (fig. 4). At age 13, (10 years after thinning) the increased height growth of thinned plots was apparent. Trees averaged 26.9 feet on the check plots, compared with trees averaging 34.5 feet on single-tree plots and 31.6 on the clump plots. At age 23, trees on the single-tree plots averaged 54 feet, on clump plots 48 feet, and on unthinned treatments 39 feet (table 1). Average annual height growth for the 20 years since treatment was 2.71, 2.42, and 1.90 feet, respectively, for the single-tree, clump, and check treatments.

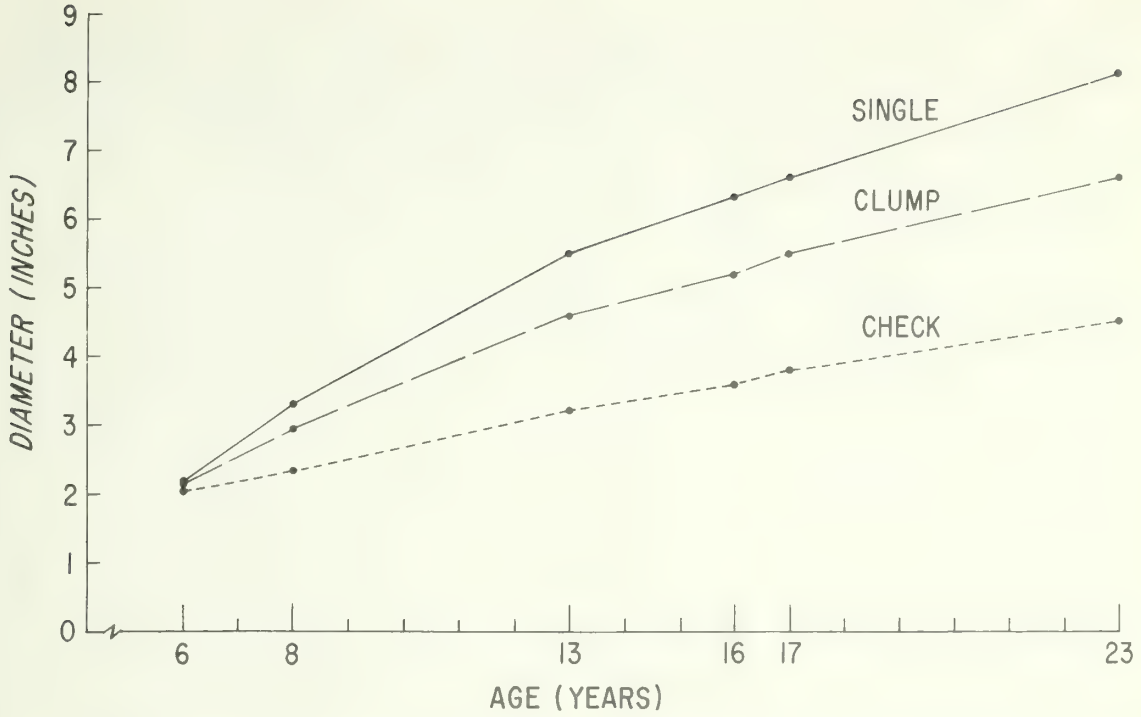

Figure 2.--Average diameters of dominant and codominant trees in each treatment, since precommercial thinning at age 3.

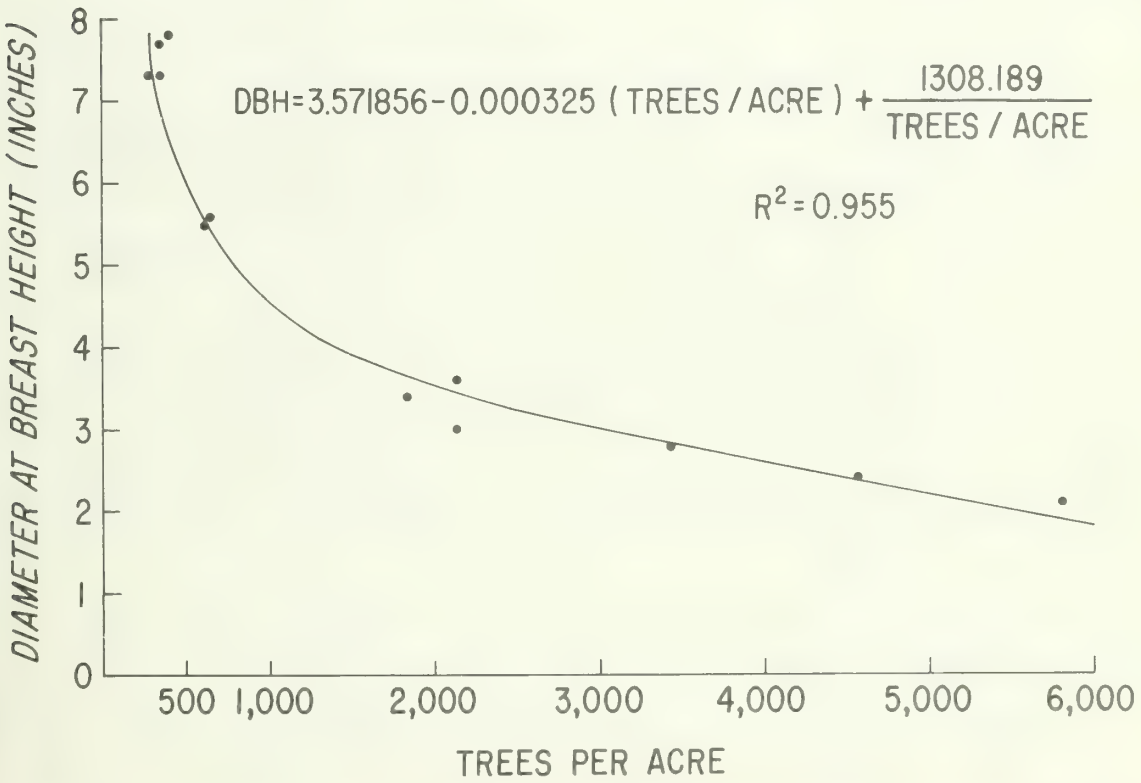

Figure 3.--At age 23, number of trees per acre sharply alters the average d.b.h. of dominant and codominant trees, especially at densities of less than 1,500 trees per acre.

Table 2.--Diameter distribution by 1-inch diameter classes, at age 23, 20 years after treatment

D.b.h. class	Single-tree	Clump	Check
		- - - Trees per acre - - -	
1	--	148	416
2	--	297	2,001
3	--	248	1,000
4	--	214	369
5	26	161	159
6	52	78	27
7	87	78	6
8	92	52	--
9	57	22	--
10	18	--	--
11	4	--	--
Total	336	1,298	3,978

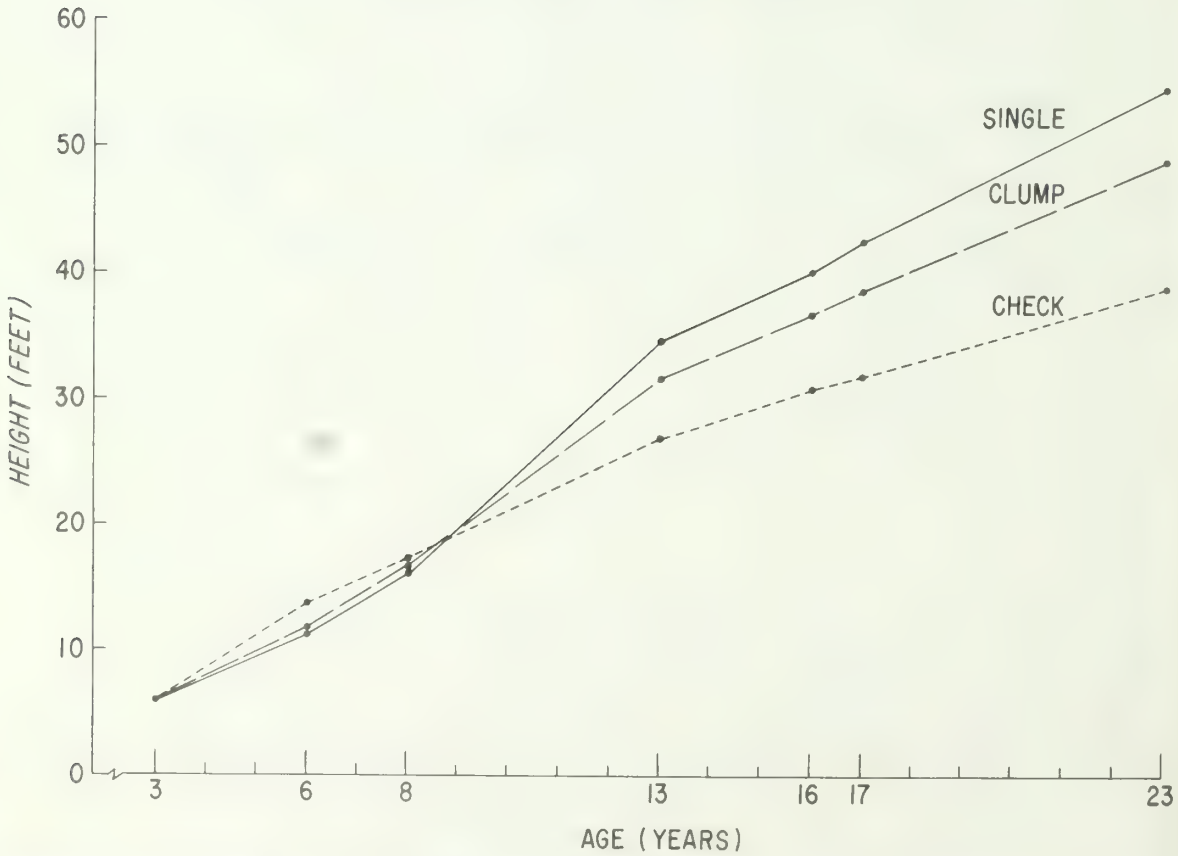

Figure 4.--Average height of dominant and codominant trees in each treatment, since precommercial thinning at age 3.

The effect of trees per acre on height growth became more critical from age 17 to 23. At age 17, the height increase was approximately 2.0 feet for each 1,000-tree reduction in stocking as reported by Collins (1967). By age 23, a 4.2-foot increase per 1,000-tree reduction was recorded (fig. 5).

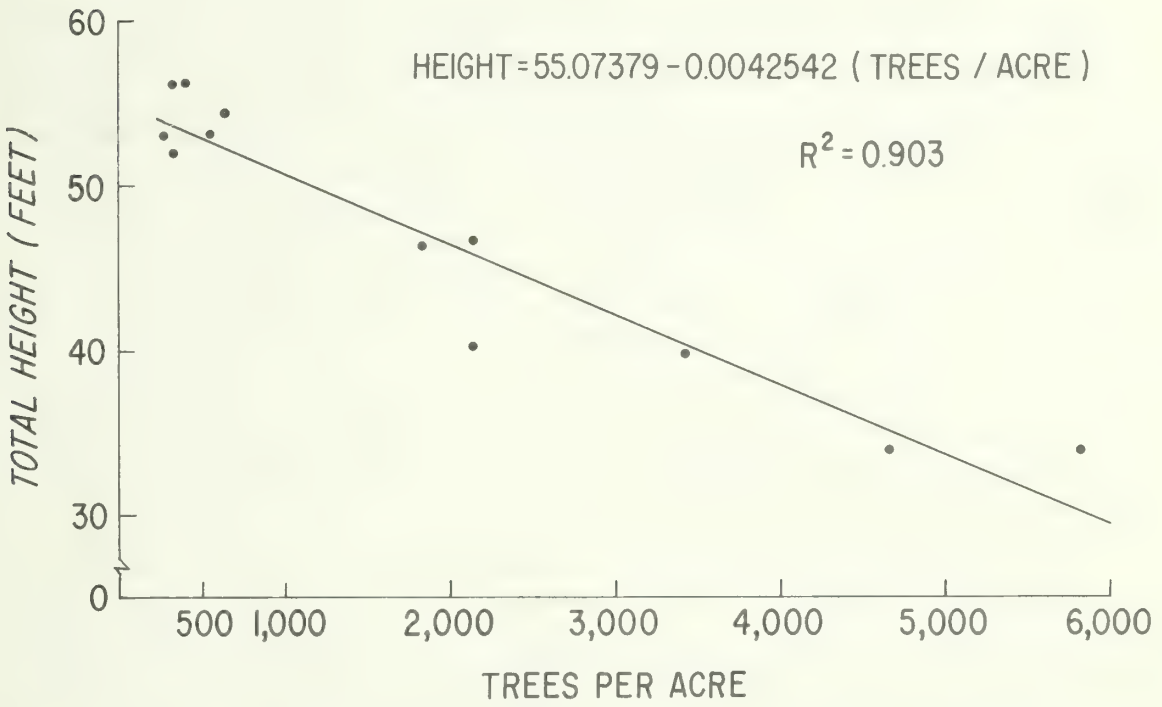

Figure 5. --The relationship between average heights of dominants and codominants and number of trees per acre indicates a 4.2-foot increase in average height for each 1,000-tree reduction in stocking at age 23.

VOLUME

Merchantable wood volume is the ultimate test of precommercial thinning. Merchantable volume resulting from precommercial thinning in this study averaged 28 cords per acre for the single-tree treatment and 19 cords for the clump treatment, compared to less than 5 cords for the unthinned treatment (table 1). Single-tree plots generally grew six times the merchantable volume of the check plots; clump-plot volumes were four times greater than check-plot volumes.

One of the unthinned plots had an unusually large volume (13.4 cords per acre), more than seven times the average of all other check plots. This plot had fewer trees than any other check plot and produced 55 percent more volume than a clump plot with almost the identical number of trees (table 1). The two plots were located in different fields. The spatial pattern of the trees in the two plots contributed to this volume difference. In the clump plot, trees were clustered with about 2 to 3 square feet of ground space per tree; in the check plot they were evenly scattered, with about 20 square feet per tree. Individual

trees in the check plot had more growing space, permitting a higher percentage of merchantable stems, taller trees, and greater volume. The topsoil in the check plot was 10 inches deeper than in the clump plot and this sometimes influences growth. However, in this study the depth of topsoil had little effect on height growth, as will be reported in the discussion.

DISCUSSION

Past farming practices in the two fields studied resulted in sheet erosion in some areas. Depth to clay, or a fine textured soil horizon (DFT), was used as a covariant in the analysis of total height at age 23. Although DFT ranged from 4.4 to 17.8 inches, it accounted for less than 5 percent of the variation in height when included in the height-density relationship. Adjustments would have changed treatment mean heights by no more than 0.8 foot, so DFT was ignored and comparisons were made using unadjusted values. For plantation slash pine on an old-field site in Florida, Barnes and Ralston (1955) found a higher correlation between height growth and DFT. They found that height growth increased significantly as DFT increased to 28 inches. The naturally seeded site treatment reflected the same relationship,although height was only weakly correlated ($r = 0.35$). The differences between these results may be caused by the naturally seeded site having a smaller range in DFT values and an extreme range of stand densities.

Height comparisons illustrate the effect extreme variations in the number of trees per acre have on site index estimates. Site index at base age 50 was calculated by the equation given for natural slash pine by Bennett (1970). The comparison of these estimates as affected by stand density is dramatic--even for adjacent plots with similar DFT (fig. 6). Within Field I, the single-tree treatment plot in block 1 had 401 trees per acre and a site index of 78. In sharp contrast, the check plot immediately to the south had 3,415 trees per acre and SI 55--a 23-foot difference in site. The check plot in block 2, Field I, immediately west of the site 78 plot, had 2,128 trees per acre and site 65--a 13-foot difference. Field II, which is overall a poorer site than Field I, also had several contrasting situations. For example, compare the single-tree treatment in block 3 with 331 trees per acre and site 72 with the check plot in block 4 with 4,565 trees per acre and site 47.

Volume production resulting from early precommercial thinning can be evaluated in terms of costs and returns. A conservative gain of 15 cords per acre resulting from precommercial thinning (table 1), would amount to an increased return of $300 per acre (priced at $20 per cord). If the cost were charged at 7-percent interest over 20 years, a precommercial thinning investment of $77 would be justified. If stumpage values are as low as $8 per cord, a $30 expenditure is feasible.

Regardless of the volume of merchantable wood in an area, harvesting costs are an important factor in marketing the product. In both thinning treatments, the merchantable wood is readily accessible as there is approximately 10 feet between rows of trees (fig. 7). In the unthinned check treatment, numerous sub-merchantable stems would deter commercial logging and therefore reduce profits. A stand as dense as 3,000 stems per acre with no more

FIELD II

CLUMP DFT 6.0 1830 SI 64	SINGLE DFT 9.0 331 SI 72	CHECK DFT 15.0 5802 SI 47	BLOCK 3
CHECK DFT 9.8 4565 SI 47	CLUMP DFT 4.4 2126 SI 56	SINGLE DFT 17.8 279 SI 74	BLOCK 4

EXPLANATIONS:

SINGLE, CLUMP, CHECK } = TREATMENT

DFT = DEPTH TO FINE TEXTURED HORIZON (INCHES)

331 = NUMBER TREES PER ACRE

SI = 50-YEAR SITE INDEX

FIELD I

BLOCK 2	BLOCK 1
SINGLE DFT 11.2 331 SI 78	CLUMP DFT 13.6 610 SI 74
CHECK DFT 14.4 2128 SI 65	SINGLE DFT 15.0 401 SI 78
CLUMP DFT 14.6 627 SI 76	CHECK DFT 10.2 3415 SI 55

Figure 6.--Diagram of field plots showing proximity of the approximately quarter-acre treatment plots and comparing density of stocking (trees per acre) and site index among plots.

Figure 7.--The single-tree plot (left photo, foreground) and clump plot (right photo), are more accessible to harvesting and other types of forestry equipment than the unthinned plot (left, background). Contrasting the densities in the left photo, the single-tree plot had 331 trees and 22.5 cords per acre at age 23, and the unthinned plot had 5,802 trees and 0.28 cord. Also notice the conspicuously shorter heights on the unthinned plot (left, background).

than 5 or 6 cords per acre is not attractive to a commercial pulpwood enterprise. If included with sales of larger trees, small-tree stands could be utilized in total tree chipping operations. This technique ensures almost complete stem-wood utilization, as well as bark and limbs, and increases the volume harvest in small-diameter, dense stands.

There would be a limited opportunity for selling even fence posts from the unthinned check treatments. Producers generally avoid stands where the trees are less than 5 inches d.b.h., or contain less than two posts per tree. Only about 5 percent of the trees in the check treatment have diameters 5 inches or greater.

At age 23, the unthinned plots would probably benefit little from release thinning. About 80 percent of the stems are in the suppressed and intermediate classes, and the crown ratio averages 25 percent. Slash pines 23 years old with crowns this small would be very slow in responding to release.

The intensive hand labor used in 1951 preparing these study plots usually is not financially feasible today. Precommercial thinning now can be accomplished with mechanized equipment such as rotary mowers, harrows, and lightweight choppers (Balmer and Williston 1973) and other machines especially designed for the work. If thinning were done at age 3, the job could be done with

relatively lightweight equipment such as a farm tractor and rotary mower. Of course, selection of equipment would depend in large part on the terrain condition. For example, cutover woodland sites with high stumps are a problem.

In comparing the two precommercial thinning methods used in this study, the cost of hand labor would rule against the single-tree method. Thinning to leave clumps can be totally mechanized and stands could be reduced to acceptable levels of density with a degree of selectivity. After the first commercial thinning of a clump treatment area, about 700 trees per acre should be left. Although mortality is difficult to anticipate, this study indicates that it is about 50 percent for the clump treatment. Compare all the clump-plot volumes (table 1); the plots with 600 to 700 surviving trees per acre at age 23 produced more than twice as much usable volume as the 2,000-tree plots. In terms of cordwood yield, low-density clump plots were very much like the single-tree plots.

Strip thinning was not used in this study, but it has been demonstrated to be an effective pattern for precommercial thinning. In a Louisiana slash pine stand thinned at age 3, Lohrey (1973) observed residual densities of 1,400 and 2,800 trees per acre and found diameter growth was comparable between strip and selective (single-tree) thinning. This led Mann and Lohrey (1974) to recommend the strip thinning practice because it is less time consuming and cheaper than selective thinning.

CONCLUSIONS

1. Young stands of natural slash pine, over-stocked with more than 2,000 stems per acre, should be identified and precommercially thinned before age 5.

2. Stocking should be reduced to less than 1,500 trees per acre; if trees are individually spaced, the stocking should be less than 700 trees per acre.

3. Cordwood yields at age 23 may be eight times as much for stands precommercially thinned early to 435 trees per acre, compared with unthinned stands carrying 3,000 or more stems per acre at age 23.

4. Thinning to single stems gives best results but requires considerable hand labor. A compromise method would be to mechanize the thinning operation and leave trees in narrow strips or clumps spaced some 10 to 12 feet apart.

5. Number of trees per acre has a significant effect on diameter and height growth. This effect was observed as early as age 17.

6. The effect of density on height growth should be considered when valuating sites occupied by a high number of trees per acre, or when comparng site indexes based on widely different levels of stocking. However, for the ange of densities normally encountered in managed stands (200 to 1,200 trees er acre), the number of trees does not seriously influence the site index stimate.

LITERATURE CITED

Balmer, William E., and Hamlin L. Williston
1973. The need for precommercial thinning. USDA For. Serv. For. Manage. Bull., 6 p. USDA For. Serv. Southeast. Area, State and Priv. For., Atlanta, Ga.

Barnes, R. L., and C. W. Ralston
1955. Soil factors related to growth and yield of slash pine plantations. Univ. Fla. Agric. Exp. Stn. Bull. 559, 23 p. Gainesville.

Bennett, Frank A.
1970. Variable-density yield tables for managed stands of natural slash pine. USDA For. Serv. Res. Note SE-141, 7 p. Southeast. For. Exp. Stn., Asheville, N. C.

Collins, Arthur B., III
1967. Density and height growth in natural slash pine. USDA For. Serv. Res. Pap. SE-27, 8 p. Southeast. For. Exp. Stn., Asheville, N. C.

Lohrey, Richard E.
1973. Precommercial thinning increases diameter and height growth of slash pine. USDA For. Serv. Res. Note SO-152, 4 p. South. For. Exp. Stn., New Orleans, La.

Mann, W. F., Jr., and R. E. Lohrey
1974. Precommercial thinning of southern pines. J. For. 72:557-560.

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USDA Forest Service Research Paper SE-165 September 1977

Biomass of Yellow-Poplar in Natural Stands in Western North Carolina

by

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and

James G. Schroeder

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Multiply		By		To Obtain
Inches	x	2.540	=	centimeters
Feet	x	.3048	=	meters
Pounds	x	.4536	=	kilograms
Cubic feet	x	.02832	=	cubic meters
Pounds per cubic foot	x	16.02	=	kilograms per cubic meter

All English units of measure in this report can be converted to metric units by multiplying by the appropriate conversion factor listed above.

Southeastern Forest Experiment Station
U.S. Department of Agriculture - Forest Service
Asheville, North Carolina

Photo caption, front cover.--Natural stand of yellow-poplar that regenerated after heavy logging in the 1920's on Pisgah National Forest in North Carolina.

Biomass of Yellow-Poplar in Natural Stands in Western North Carolina[1,2]

by

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and

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Abstract.--Aboveground biomass was determined for yellow-poplar (Liriodendron tulipifera L.) trees 6 to 28 inches d.b.h. growing in natural, uneven-aged mountain cove stands in western North Carolina. Average green weight of total tree biomass without foliage ranged from 336 pounds for 6-inch trees to 14,336 pounds for 28-inch trees. The average tree contained 91 percent of the total dry weight in the stem material, with 9 percent found in the branches. On the average, 23 percent of branch dry weight was bark and 77 percent was wood compared to stem material which contained 15 percent bark and 85 percent wood. Trends in biomass proportions are discussed; and specific gravity, moisture content, and green weight per cubic-foot data are presented for the total tree and its components. Tables developed from regression equations show weight and volume of the total tree and its components by d.b.h. and total height class.

Keywords: Biomass, component proportions, Liriodendron tulipifera L., prediction equations, volume, weight.

Competition for timber, escalating costs, and the energy shortage have forced wood users to consider maximizing total tree use. Pulpwood trees and upper stems and tops of sawtimber trees are now being chipped in the field for use in reconstituted paper and board products. The old method of estimating volume or weight by the merchantable saw-log stem no longer provides sufficient information for utilizing the total tree. More weight and volume information is needed to determine aboveground total tree biomass.

This paper discusses green volume and green and dry weights of aboveground biomass of commercial-size yellow-poplar growing in natural, uneven-aged mountain cove stands in western North Carolina. The wood and bark proportions of tree biomass are discussed on a weight basis. The equations

[1]This study was conducted in cooperation with and through the financial assistance of the Range, Timber, and Wildlife Program Area of Region 8 of the National Forest System. Field personnel were provided by the Pisgah District of the Pisgah National Forest. Cooperation and assistance were also received from the Canton Hardwood Lumber Company and the Timberlands Division of Champion International Corporation.

[2]Presented at the Third Annual Hardwood Symposium, Cashiers, North Carolina, May 1975.

presented predict weight and volume of the total tree and its components (wood, bark, saw logs, total stem, and branches). Wood and bark specific gravity, moisture content, and green weight per cubic foot are presented for the total tree and its component parts. In this report, total tree refers only to above-ground wood and bark and does not include stump, roots, or foliage.

PROCEDURE

FIELD

A stratified random sample of 39 trees was selected from natural, closed, uneven-aged mountain cove stands of yellow-poplar. The sample trees were from a pulpwood stand and a mature sawtimber stand, both located on the Pisgah Ranger District of the Pisgah National Forest in western North Carolina. Site index (age 50) averaged 100 to 110. One to five trees were selected from each even-inch d.b.h. class from 6 to 28 inches. Means and ranges of tree measurements are shown in table 1.

Table 1.--Means and ranges of yellow-poplar tree measurements for each d.b.h. strata sampled

D.b.h. class (inches)	Sample trees	D.b.h.		Total height		Merchantable height[1/]		Age		Form class	
		Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range	Avg.	Range
	Number	Inches		Feet				Years			
6	5	6.1	5.8- 6.5	61	53- 69	--	--	32	21-47	76	73-79
8	5	7.9	7.6- 8.1	70	65- 80	--	--	30	21-42	78	73-83
10	5	10.1	9.9-10.3	90	77-102	--	--	60	47-75	80	79-83
12	5	11.9	11.7-12.3	105	93-118	44	34- 48	67	61-75	86	83-91
14	5	14.2	13.9-14.5	102	85-110	60	52- 68	62	59-67	81	79-84
16	3	15.9	15.6-16.2	118	108-132	71	62- 86	63	60-68	82	79-85
18	3	18.0	17.7-18.3	111	107-113	65	56- 76	60	56-62	83	82-84
20	1	19.1	--	116	--	68	--	68	--	87	--
22	2	21.5	21.5-21.5	126	120-132	80	76- 83	72	68-75	82	78-85
24	3	24.3	24.0-24.7	137	130-147	93	87-102	67	65-72	83	80-85
26	1	25.6	--	128	--	82	--	73	--	84	--
28	1	28.4	--	129	--	94	--	81	--	80	--
All classes	39	13.9	5.8-28.4	99	53-147	67	34-102	56	21-81	81	73-91

[1/] Height to 8-inch d.i.b. merchantable top.

After felling and limbing, the main stem of each tree was bucked into merchantable saw logs and pulpwood. Saw logs 8 to 16 feet long were cut from the main stem to a 8-inch d.i.b. top or a degrading quality indicator such as large knots. Saw-log stem top d.i.b. averaged 9.5 inches. All material between the saw-log merchantable top and the 4-inch top was classed as pulpwood, and material between the 4- and 2-inch top was classed as topwood. The crown was cut up and separated into three categories: (1) large branches ($\geq$ 2.0 inches d.o.b.), (2) medium branches ($\geq$ 0.6 and $\leq$ 1.9 inches d.o.b.),

(3) small branches (≤ 0.5 inches d.o.b.). The tip of the stem (2 inches d.i.b. to top) was included as branch material in the analysis. All crown material and pulpwood were weighed to the nearest 0.25 pound. Saw logs were weighed individually to the nearest pound.

Disks were removed from the butt of each tree, at each bucking point, at the points where d.i.b. measured 4 and 2 inches, and from branches randomly selected from each branch category. Immediately after being cut, the disks were calipered and weighed with and without bark. A representative sample of bark and wood was removed from each disk, weighed, and sealed in a polyethylene bag for laboratory analysis. From these disks the moisture content and specific gravity of wood and bark were determined.

LABORATORY

Specific gravity was computed on a green volume and ovendry basis. To determine moisture content, samples were dried to a constant weight at 103° C and their moisture content was computed on an ovendry basis. Percentage of bark was determined on a weight basis from cross-sectioned samples. Weighted values for moisture content, specific gravity, and percentage of bark in stem, branches, and total tree were calculated by weighting disk values in proportion to the volume of the component they represented. Weighted values for moisture content were used to convert component green weight to ovendry weight.

The following equation was used to calculate green weight per cubic foot separately for wood and bark on the basis of the weighted values for specific gravity and moisture content:

$$\text{Green weight per cubic foot} = \left(1 + \frac{\text{weighted moisture content in percent}}{100}\right) \times (62.4 \times \text{weighted specific gravity}) \qquad (1)$$

The green cubic-foot volume of wood and bark was computed by dividing component weight by its green weight per cubic foot. Green cubic-foot volume (wood and bark combined) was computed by adding green volume of wood to the green volume of bark.

ANALYSIS

Simple linear equations were developed to predict green and dry weights of wood and bark in the total tree and components. Independent variables were: diameter at breast height (D), total height (Th), merchantable height, crown ratio, and form class both separately and in various combinations. Equations were also developed to predict green cubic-foot volume of wood and bark separately and combined.

For determining both weights and volumes, the independent variable giving the closest correlations was D^2Th. Grouping of the data into D^2Th classes indicated that the variance of Y increased with increasing D^2Th. A logarithmic transformation (to the base 10) was used to obtain a homogeneous

variance as assumed in regression analysis. Thus, regression models for tree and component weights and volumes with D^2Th were calculated using the equation:

$$\text{Log } Y = b_o + b_1 \text{ Log } D^2Th + e \quad (2)$$

where: Y = weight or volume of component,
D = d.b.h. in inches,
Th = total tree height in feet,
e = experimental error, and
b_o, b_1 = constants.

When logarithmic estimates are converted back to original units, they are biased downward because the antilogarithm of the estimated means gives the geometric rather than the arithmetic mean.[3] To account for this bias a correction factor was computed using a procedure described by Baskerville[4] and was applied to each equation. The form of the equation including the correction factor was:

$$\text{Log } Y = b_o + b_1 \text{ Log } (D^2Th) + \frac{S^2_{y \cdot x}}{2} \quad (3)$$

$$= b'_o + b_1 \text{ Log } D^2Th \quad (4)$$

where: $S^2_{y \cdot x}$ = error mean square from regression analysis and b'_o is the intercept adjusted by the correction factor.

Separate prediction equations were developed for the pulpwood and sawtimber trees. Statistical tests[5] of the slopes and intercepts of these equations indicated there was no significant difference in the slopes or intercepts at the 0.01 probability level for either the total tree and stem weights or the volume equations. Therefore, the pulpwood and sawtimber trees were combined and one series of equations developed for trees 6 to 28 inches d.b.h.

RESULTS

TOTAL TREE BIOMASS

Green and dry weight of the total tree (excluding foliage) and proportion of tree weight in wood and bark are shown in table 2. Green weight of the total tree ranged from 336 pounds for 6-inch trees to 14,336 pounds for a 28-inch tree. Assuming the trees were composed of wood, bark, and water, 51 percent of their green weight was water; 41 percent was wood; and 8 percent was bark. On a dry-weight basis, trees averaged 85 percent of their weight in wood and 15 percent in bark. Component proportions differed slightly for

[3] Cunia, T. 1964. Weighted least squares method and construction of volume tables. For. Sci. 10:180-191.

[4] Baskerville, G. L. 1972. Use of logarithmic regression in the estimation of plant biomass. Can. J. For. Res. 2:49-53.

[5] Snedecor, G. W., and W. G. Cochran. 1967. Statistical methods. 6th ed. p. 432-436. Iowa State Univ. Press, Ames.

green-weight measurements because of differences in component moisture content.

The proportion of tree dry weight found in branches ranged from 7 to 12 percent and averaged 9 percent (table 3). Pulpwood trees had 2 to 5 percent more of their dry weight in branches than the sawtimber trees.

The green and dry weight of all wood and bark in the tree and distribution of wood and bark throughout the tree are presented in tables 4 and 5. As can be seen from these tables, wood and bark are not distributed evenly

Table 2.--Average green and dry weight of the total tree and proportion of the tree in wood and bark for yellow-poplar trees 6 to 28 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree green weight	Tree component proportions (green)		Total tree dry weight	Tree component proportions (dry)	
				Wood	Bark		Wood	Bark
	Feet	Number	Pounds	Percent		Pounds	Percent	
6	61	5	336	80	20	145	83	17
8	70	5	649	81	19	292	85	15
10	90	5	1,316	82	18	628	85	15
12	105	5	1,928	82	18	931	83	17
14	102	5	2,876	82	18	1,382	84	16
16	118	3	3,830	83	17	1,951	85	15
18	111	3	4,770	81	19	2,314	82	18
20	116	1	6,036	82	18	2,901	83	17
22	126	2	8,051	84	16	4,050	87	13
24	136	3	9,712	83	17	5,021	84	16
26	128	1	13,026	84	16	6,842	86	14
28	129	1	14,336	84	16	7,570	86	14
Average	--	--	3,589	83	17	1,799	85	15

Table 3.--Average green and dry weight of the total tree and proportion of the tree in main stem[1/] and branches[2/] for yellow-poplar trees 6 to 28 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree green height	Tree component proportions (green)		Total tree dry weight	Tree component proportions (dry)	
				Stem	Branches		Stem	Branches
	Feet	Number	Pounds	Percent		Pounds	Percent	
6	61	5	336	87	13	145	88	12
8	70	5	649	87	13	292	88	12
10	90	5	1,316	86	14	628	88	12
12	105	5	1,928	94	7	931	94	7
14	102	5	2,876	90	10	1,382	91	9
16	118	3	3,830	90	10	1,951	92	8
18	111	3	4,770	88	12	2,314	90	10
20	116	1	6,036	88	12	2,901	90	10
22	126	2	8,051	89	11	4,050	90	10
24	136	3	9,712	91	9	5,021	92	8
26	128	1	13,026	92	8	6,842	93	7
28	129	1	14,336	92	8	7,570	92	8
Average	--	--	3,589	90	10	1,799	91	9

[1/] Stem material to 2-inch d.i.b. top.
[2/] Includes all branch material and tip of main stem.

Table 4.--Average green and dry weight of wood in the total tree and distribution of wood in main stem and branches in yellow-poplar trees 6 to 28 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree wood weight	Proportion of wood in--							
				Main stem[1]				Branches			
				Saw log	Pulp-wood	Top wood	Total stem	Large	Medium	Small	All branches
	Feet	Number	Pounds	- - - - - - - - - - - - - - - - Percent - - - - - - - - - - - - - - - -							
				GREEN							
6	61	5	268	--	66	24	90	0	7	3	10
8	70	5	526	--	80	10	90	0	7	3	10
10	90	5	1,075	--	84	4	88	2	7	3	12
12	105	5	1,583	68	25	2	95	1	3	1	5
14	102	5	2,358	80	11	1	92	3	4	1	8
16	118	3	3,200	82	9	1	92	5	2	1	8
18	111	3	3,876	78	11	1	90	6	3	1	10
20	116	1	4,953	78	11	1	90	6	3	1	10
22	126	2	6,786	82	8	0[2]	90	7	2	1	10
24	137	3	8,075	86	6	0[2]	92	6	2	0[2]	8
26	128	1	10,934	79	14	0[2]	93	5	2	0[2]	7
28	129	1	12,014	84	9	0[2]	93	6	1	0[2]	7
Average	--	--	2,976	81	9	1	91	5	3	1	9
				DRY							
6	61	5	121	--	64	24	88	0	8	4	12
8	70	5	248	--	80	9	89	0	8	3	11
10	90	5	532	--	84	4	88	3	7	2	12
12	105	5	776	67	26	2	95	1	3	1	5
14	102	5	1,161	80	11	1	92	3	4	1	8
16	118	3	1,656	82	9	1	92	5	2	1	8
18	111	3	1,898	78	12	1	91	6	2	1	9
20	116	1	2,422	78	12	1	91	5	3	1	9
22	126	2	3,517	83	8	0[2]	91	6	2	1	9
24	137	3	4,225	86	6	0[2]	92	6	2	0[2]	8
26	128	1	5,880	80	14	0[2]	94	4	2	0[2]	6
28	129	1	6,512	84	9	0[2]	93	6	1	0[2]	7
Average	--	--	1,524	81	10	1	92	4	3	1	8

[1] Main stem to 2-inch d.i.b. top.
[2] Less than one-half of one percent.

Table 5.--Average green and dry weight of bark in the total tree and distribution of bark in main stem and branches in yellow-poplar trees 6 to 28 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Total tree bark weight	Proportion of bark in--							
				Main stem[1]				Branches			
				Saw log	Pulp-wood	Top wood	Total stem	Large	Medium	Small	All branches
	Feet	Number	Pounds	- - - - - - - - - - - - - - - - Percent - - - - - - - - - - - - - - - -							
				GREEN							
6	61	5	68	--	53	23	76	0	12	12	24
8	70	5	122	--	68	10	78	0	11	11	22
10	90	5	241	--	71	5	76	4	12	8	24
12	105	5	345	63	22	3	88	1	8	3	12
14	102	5	518	70	10	1	81	6	9	4	19
16	118	3	630	67	9	1	81	10	6	3	19
18	111	3	894	68	11	1	80	10	6	4	20
20	116	1	1,093	66	13	1	80	10	7	3	20
22	126	2	1,265	73	8	1	82	11	4	3	18
24	137	3	1,637	77	7	0[2]	84	10	4	2	16
26	128	1	2,092	71	15	0[2]	86	8	4	2	14
28	129	1	2,322	73	11	0[2]	84	12	2	2	16
Average	--	--	612	71	10	1	82	8	6	4	18
				DRY							
6	61	5	25	--	60	24	84	0	8	8	16
8	70	5	43	--	65	10	85	0	8	7	15
10	90	5	96	--	80	5	85	3	8	4	15
12	105	5	155	64	24	2	90	3	5	2	10
14	102	5	221	74	11	1	86	5	6	3	14
16	118	3	295	77	10	1	88	6	4	2	12
18	111	3	416	74	12	1	87	7	4	2	13
20	116	1	479	70	15	1	86	8	4	2	14
22	126	2	533	76	9	1	86	9	3	2	14
24	137	3	796	80	7	0[2]	87	9	3	1	13
26	128	1	962	73	16	0[2]	89	6	3	2	11
28	129	1	1,058	72	13	0[2]	85	12	2	1	15
Average	--	--	276	75	10	1	86	7	4	3	14

[1] Main stem to 2-inch d.i.b. top.
[2] Less than one-half of one percent.

throughout the tree; the saw-log portion of the tree contains 81 percent of the dry wood, but only 75 percent of the dry bark. Branches contain 8 percent of the dry wood compared to 14 percent of the dry bark. On the average, the pulpwood section of the total tree contains equal proportions of the wood and bark (10 percent). The topwood section also contains equal proportions of the total wood and bark (1 percent).

BRANCH BIOMASS

When branches were analyzed as a separate entity, the proportion of dry weight in wood ranged from 74 to 81 percent and proportion of dry weight in bark ranged from 19 to 26 percent (table 6). On the average, 77 percent of branch dry weight was wood and 23 percent was bark.

Branches make up 7 to 12 percent of the dry weight of the total tree, depending on tree size (table 3). On the average, 12 percent of the branch dry weight was in small branches, 32 percent was in medium branches, and 56 percent was in large branches. The proportions in branch size varied greatly with tree size (fig. 1); the proportion of large branches increased rapidly with

Table 6.--Average green and dry weight of the branches and proportion of branches in wood and bark for yellow-poplar trees 6 to 28 inches d.b.h.

D.b.h. class (inches)	Average total height	Sample trees	Branch weight (green)	Branch proportion in green--		Branch weight (dry)	Branch proportion in dry--	
				Wood	Bark		Wood	Bark
	Feet	Number	Pounds	Percent		Pounds	Percent	
6	61	5	44	65	35	17	79	21
8	70	5	84	67	33	34	81	19
10	90	5	188	69	31	77	80	20
12	105	5	121	64	36	51	74	26
14	102	5	283	67	33	125	76	24
16	118	3	383	69	31	163	78	22
18	111	3	557	68	32	225	76	24
20	116	1	693	68	32	276	76	24
22	126	2	886	73	27	393	80	20
24	136	3	870	70	30	416	75	25
26	128	1	999	71	29	457	77	23
28	129	1	1,204	70	30	632	75	25
Average	--	--	351	69	31	156	77	23

Figure 1.--Proportion of yellow-poplar crown in small, medium, and large branches by tree size.

increasing tree size while the proportion of medium and small branches decreased with increasing tree size. When branches were separated into wood and bark, large branches averaged 78 percent wood and 22 percent bark, medium branches averaged 77 percent wood and 23 percent bark, and small branches averaged 67 percent wood and 33 percent bark.

MAIN STEM BIOMASS

When the main stem was analyzed as a separately entity, the proportion of dry weight in wood averaged 85 percent and 15 percent was bark (table 7).

Table 7.--Average green and dry weight of the stem[1/] and proportion of stem in wood and bark in yellow-poplar trees 6 to 28 inches d.b.h.

D.b.h. class (inches)	Average Total height	Sample trees	Stem weight (green)	Stem proportion in green--		Stem weight (dry)	Stem proportion in dry--	
				Wood	Bark		Wood	Bark
	Feet	Number	Pounds	Percent		Pounds	Percent	
6	61	5	292	82	18	128	84	16
8	70	5	565	83	17	258	85	15
10	90	5	1,128	84	16	551	85	15
12	105	5	1,807	83	17	880	84	16
14	102	5	2,593	84	16	1,257	85	15
16	118	3	3,447	85	15	1,788	85	15
18	111	3	4,213	83	17	2,089	83	17
20	116	1	5,343	84	16	2,625	85	15
22	126	2	7,165	86	14	3,657	88	12
24	137	3	8,842	84	16	4,605	85	15
26	128	1	12,027	85	15	6,385	87	13
28	129	1	13,132	86	14	6,938	88	12
Average	--	--	3,238	84	16	1,643	85	15

[1/] Stem material to 2-inch d.i.b. top.

PHYSICAL PROPERTIES

Wood and bark specific gravity, moisture content, and green weight per cubic foot for the total tree and its components are presented in table 8. Wood specific gravity and moisture content did not vary significantly with tree size. Wood specific gravity for the total tree averaged 0.407--within the average range reported for the species.[6] Branches had the highest wood specific gravity, averaging 0.424, and saw-log wood the lowest, averaging 0.406. Average wood moisture content ranged from 103 percent in the saw-log section to 111 percent in the topwood section and averaged 104 percent for all wood in the tree. Wood green weight per cubic foot averaged 51.8 pounds in the stem, 54.4 pounds in the branches, and 51.8 pounds in the total tree.

[6]U.S. Forest Products Laboratory. 1974. Wood handbook: Wood as an engineering material. USDA Agric. Handb. 72 rev., p. 4-44.

Table 8.--Average wood and bark specific gravity, moisture content, and green weight per cubic foot for yellow-poplar trees and tree components

Tree component	Average and standard deviation		
	Specific gravity	Moisture content	Green weight per cubic foot
		Percent	Pounds
	WOOD		
Total tree	0.407 ± 0.029	104 ± 13	51.8 ± 3.5
Total stem	.407 ± .030	104 ± 14	51.8 ± 3.7
Saw log section	.406 ± .029	103 ± 13	51.5 ± 3.8
Pulpwood section	.413 ± .037	103 ± 18	52.3 ± 4.6
Topwood section	.419 ± .035	111 ± 13	55.2 ± 4.4
Branches	.424 ± .026	106 ± 15	54.4 ± 3.9
	BARK		
Total tree	0.325 ± 0.028	142 ± 36	49.1 ± 8.4
Total stem	.332 ± .034	126 ± 29	46.8 ± 8.4
Saw log section	.328 ± .035	124 ± 28	46.1 ± 8.0
Pulpwood section	.354 ± .027	123 ± 35	49.3 ± 8.2
Topwood section	.350 ± .035	151 ± 27	54.8 ± 6.5
Branches	.285 ± .048	247 ± 66	59.9 ± 3.1

Specific gravity of bark was consistently lower than the specific gravity of wood, averaging 0.325 for the total tree (table 8). Branch-bark specific gravity averaged 0.285 and was on the average lower than stembark specific gravity (0.332).

Bark moisture content averaged 142 percent for the total tree, considerably higher than the corresponding value for wood (table 8). Branchbark moisture content (247 percent) was significantly higher than stembark moisture content (126 percent). The higher branchbark moisture content was probably due to the higher proportion of inner bark which has a high moisture content and the season of the year the trees were sampled.

Bark moisture content has been reported to vary with the season of the year; Phillips and Schroeder[7] found bark moisture content highest during and just following leaf development and lowest at the time of leaf fall. Since our trees were sampled during April and May, it is possible that the bark moisture content was higher than if we had sampled in the fall of the year. For example, Phillips and Schroeder's highest seasonal green bark weight was 49.6 pounds per cubic foot, while the average weight for the year was 46.1 pounds per cubic foot. The green weight of total tree bark in our study is 49.1 pounds, close to the maximum value reported. Therefore, when considering an average value for the year, our bark should possibly be approximately 3.0 pounds per cubic foot lighter.

[7] Phillips, Douglas R., and James G. Schroeder. 1973. Some physical properties of yellow-poplar wood and bark. Part 1. - Seasonal moisture content. Wood Sci. 5:265-269.

Average bark green weight per cubic foot varied considerably within the tree, ranging from 46.1 pounds per cubic foot for saw-log bark to 59.9 pounds per cubic foot for branchbark (table 8). Green weight per cubic foot of wood and bark combined averaged 51.4 pounds for the total tree, 50.8 pounds in the main stem, and 56.2 pounds in branch material.

EQUATIONS

A series of equations was developed to predict total tree and tree component weight and volume based on the 39 sample trees. Equations for predicting weight of the total tree and its green and dry component parts are shown in table 9. Equations for predicting total tree and tree component wood and bark green cubic-foot volume are presented in table 10. Also included in tables 9 and 10 are the coefficients of determination and standard errors of estimate for each equation. The coefficients of determination indicate a high degree of linear association between the independent variable (D^2Th) and total tree or component weight and volume. Poorest association occurred in equations predicting branch weight and volume. Crown components had a higher degree of variability than other tree components, as indicated by the coefficients of determination.

The downward bias, occurring when logarithmic estimates were converted to untransformed units, ranged from less than 1 percent for total tree and stem equations to over 6 percent for branch equations. Although the bias was negligible for total tree and stem equations, a correction factor was applied to each equation for consistency.

YIELD TABLES

Equations from tables 9 and 10 were used to develop tables of biomass weight and volume. Predicted green and dry weights of wood and bark and wood excluding bark in the total tree, main stem, and branches are presented in tables 11-18 by d.b.h. and total height classes. Predicted green cubic-foot volume of wood and bark and wood excluding bark in the total tree, main stem, and branches are presented in tables 19-22. The predicted weight or volume of bark in a tree or component can be estimated by substracting the value in the table for wood excluding bark from the corresponding value in the table for wood and bark combined.

SUMMARY

This paper discusses the aboveground biomass of yellow-poplar trees 6 to 28 inches d.b.h. growing in natural, uneven-aged, mountain cove stands in western North Carolina. Regression equations were formulated to predict the weight and volume of the total tree and its components. Tables developed with these equations show the weight and volume of wood and bark, and wood excluding bark for the total tree and its components by d.b.h. and total height classes.

Trees with the same d.b.h. and total height may vary considerably in weight and volume because of differences in crown size, taper, and weight per

Table 9.--Regression equations for estimating green and dry weight of the aboveground biomass of natural yellow-poplar trees 6 to 28 inches d.b.h. and tree component parts using d.b.h. and total height as the independent variables

Weight (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]
TOTAL TREE (EXCLUDING LEAVES)[3/]			
Green	$\text{Log}_{10}\ Y = -0.69614 + 0.96067\ \text{Log}_{10}\ D^2Th$	0.99	0.049
Dry	$\text{Log}_{10}\ Y = -1.22162 + 1.00962\ \text{Log}_{10}\ D^2Th$	.99	.046
ALL WOOD IN TREE[3/]			
Green	$\text{Log}_{10}\ Y = -0.83371 + 0.97283\ \text{Log}_{10}\ D^2Th$	.99	.050
Dry	$\text{Log}_{10}\ Y = -1.31186 + 1.01330\ \text{Log}_{10}\ D^2Th$	.99	.050
ALL BARK IN TREE [3/]			
Green	$\text{Log}_{10}\ Y = -1.20965 + 0.90556\ \text{Log}_{10}\ D^2Th$	.98	.055
Dry	$\text{Log}_{10}\ Y = -1.94536 + 0.99070\ \text{Log}_{10}\ D^2Th$	.98	.063
WOOD AND BARK IN STEM FROM STUMP TO SAW-LOG MERCHANTABLE TOP FOR TREES >11.5 INCHES D.B.H.[4/]			
Green	$\text{Log}_{10}\ Y = -1.40405 + 1.09136\ \text{Log}_{10}\ D^2Th$	.98	.049
Dry	$\text{Log}_{10}\ Y = -1.92791 + 1.14055\ \text{Log}_{10}\ D^2Th$	.98	.049
WOOD IN STEM FROM STUMP TO SAW-LOG MERCHANTABLE TOP FOR TREES >11.5 INCHES D.B.H.[4/]			
Green	$\text{Log}_{10}\ Y = -1.54143 + 1.10526\ \text{Log}_{10}\ D^2Th$	.98	.051
Dry	$\text{Log}_{10}\ Y = -2.07644 + 1.15782\ \text{Log}_{10}\ D^2Th$	.98	.053

continued

Table 9.--Regression equations for estimating green and dry weight of the aboveground biomass of natural yellow-poplar trees 6 to 28 inches d.b.h. and tree component parts using d.b.h. and total height as the independent variables (continued)

Weight (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]
BARK IN STEM FROM STUMP TO SAW-LOG MERCHANTABLE TOP FOR TREES >11.5 INCHES D.B.H.[4/]			
Green	$\text{Log}_{10}\ Y = -1.88576 + 1.01997\ \text{Log}_{10}\ D^2Th$	0.95	0.069
Dry	$\text{Log}_{10}\ Y = -2.32150 + 1.04433\ \text{Log}_{10}\ D^2Th$	.95	.071
WOOD AND BARK IN STEM FROM STUMP TO 2 INCH D.I.B. TOP[3/]			
Green	$\text{Log}_{10}\ Y = -0.81474 + 0.97694\ \text{Log}_{10}\ D^2Th$	.99	.040
Dry	$\text{Log}_{10}\ Y = -1.33025 + 1.02493\ \text{Log}_{10}\ D^2Th$	.99	.042
WOOD IN STEM FROM STUMP TO 2 INCH D.I.B. TOP[3/]			
Green	$\text{Log}_{10}\ Y = -0.92750 + 0.98533\ \text{Log}_{10}\ D^2Th$	.99	.043
Dry	$\text{Log}_{10}\ Y = -1.41983 + 1.02925\ \text{Log}_{10}\ D^2Th$	.99	.045
BARK IN STEM FROM STUMP TO 2 INCH D.I.B. TOP[3/]			
Green	$\text{Log}_{10}\ Y = -1.42008 + 0.93339\ \text{Log}_{10}\ D^2Th$	.99	.051
Dry	$\text{Log}_{10}\ Y = -2.05248 + 1.00116\ \text{Log}_{10}\ D^2Th$	.98	.070
WOOD AND BARK IN BRANCHES[3/]			
Green	$\text{Log}_{10}\ Y = -1.15689 + 0.83663\ \text{Log}_{10}\ D^2Th$	.80	.211
Dry	$\text{Log}_{10}\ Y = -1.71827 + 0.88172\ \text{Log}_{10}\ D^2Th$	.83	.206

continued

Table 9.--Regression equations for estimating green and dry weight of the aboveground biomass of natural yellow-poplar trees 6 to 28 inches d.b.h. and tree component parts using d.b.h. and total height as the independent variables (continued)

Weight (Y)	Regression equation[1/]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$)[2/]
WOOD IN BRANCHES[3/]			
Green	$\text{Log}_{10}\ Y = -1.40010 + 0.85422\ \text{Log}_{10}\ D^2Th$	0.79	0.225
Dry	$\text{Log}_{10}\ Y = -1.76294 + 0.86612\ \text{Log}_{10}\ D^2Th$	.80	.219
BARK IN BRANCHES[3/]			
Green	$\text{Log}_{10}\ Y = -1.49101 + 0.79882\ \text{Log}_{10}\ D^2Th$	.83	.185
Dry	$\text{Log}_{10}\ Y = -2.60277 + 0.93682\ \text{Log}_{10}\ D^2Th$	.89	.172

[1/] $\text{Log}_{10}\ Y = b_0' + b_1\ \text{Log}_{10}\ D^2Th$

where: Y = weight of tree or component in pounds,
D = d.b.h. in inches,
Th = total height in feet.

[2/] Standard error of estimate in Log_{10} form.

[3/] Regression equations based on 39 trees 6 to 28 inches d.b.h.

[4/] Regression equations based on 24 trees 12 to 28 inches d.b.h.

Table 10.--Regression equations for estimating green cubic foot volume of the aboveground biomass of natural yellow-poplar trees 6 to 28 inches d.b.h. and tree component parts using d.b.h. and total height as the independent variables

Cubic foot volumes	Regression equation [1]	Coefficient of determination (R^2)	Standard error ($S_{y.x}$) [2]
TOTAL TREE (EXCLUDING LEAVES) [3]			
Wood	$\text{Log}_{10} Y = -2.60833 + 0.98740 \text{ Log}_{10} D^2Th$	0.99	0.036
Bark	$\text{Log}_{10} Y = -3.34254 + 1.01348 \text{ Log}_{10} D^2Th$	.99	.057
Wood & bark	$\text{Log}_{10} Y = -2.53544 + 0.99215 \text{ Log}_{10} D^2Th$	.99	.034
STEM FROM STUMP TO A SAW-LOG MERCHANTABLE TOP FOR TREES > 11.5 INCHES D.B.H. [4]			
Wood	$\text{Log}_{10} Y = -3.36739 + 1.13164 \text{ Log}_{10} D^2Th$	.99	.036
Bark	$\text{Log}_{10} Y = -3.58003 + 1.03884 \text{ Log}_{10} D^2Th$	.95	.066
Wood & bark	$\text{Log}_{10} Y = -3.19278 + 1.11325 \text{ Log}_{10} D^2Th$	.99	.036
STEM FROM STUMP TO 2 INCH D.I.B. TOP [3]			
Wood	$\text{Log}_{10} Y = -2.70952 + 1.00212 \text{ Log}_{10} D^2Th$	.99	.031
Bark	$\text{Log}_{10} Y = -3.59784 + 1.05620 \text{ Log}_{10} D^2Th$	.98	.066
Wood & bark	$\text{Log}_{10} Y = -2.66141 + 1.01119 \text{ Log}_{10} D^2Th$	.99	.030
BRANCH MATERIAL (EXCLUDING LEAVES) [3]			
Wood	$\text{Log}_{10} Y = -3.09526 + 0.84474 \text{ Log}_{10} D^2Th$	.80	.213
Bark	$\text{Log}_{10} Y = -3.34471 + 0.81757 \text{ Log}_{10} D^2Th$	.84	.180
Wood & bark	$\text{Log}_{10} Y = -2.90517 + 0.83679 \text{ Log}_{10} D^2Th$	.82	.202

[1] $\text{Log}_{10} Y = b_0' + b_1 \text{ Log}_{10} D^2Th$

where: Y = cubic foot volume of tree component,
D = d.b.h. in inches,
Th = total height in feet.

[2] Standard error of estimates in Log_{10} form.
[3] Regression equations based on 39 trees 6 to 28 inches d.b.h.
[4] Regression equations based on 14 trees 12 to 28 inches d.b.h.

cubic foot. Therefore, these equations and tables should not be used indiscriminately over the range of yellow-poplar. They should only be applied to similar aged trees growing in natural closed stands which have taper rates and weight per cubic-foot values similar to the trees sampled.

APPENDIX

Table 11.--Predicted weight of total tree wood and bark for yellow-poplar trees[1/]

D.b.h.	Total tree height (feet)[2/]										
(inches)	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	GREEN[3/]										
6	218	270	321	373	424						
7	293	363	432	501	570	638					
8	378	469	559	648	737	825	913				
9		588	701	812	924	1,034	1,145	1,254			
10			858	995	1,131	1,266	1,401	1,536	1,670		
11			1,030	1,195	1,358	1,521	1,683	1,844	2,005		
12			1,218	1,412	1,605	1,798	1,989	2,180	2,370	2,559	
13			1,420	1,647	1,872	2,097	2,320	2,542	2,764	2,985	
14				1,899	2,159	2,417	2,675	2,931	3,187	3,442	3,696
15				2,168	2,465	2,760	3,054	3,347	3,639	3,929	4,219
16				2,454	2,790	3,124	3,457	3,789	4,119	4,448	4,776
17				2,757	3,135	3,510	3,884	4,257	4,628	4,998	5,366
18				3,077	3,499	3,918	4,335	4,751	5,165	5,578	5,989
19					3,882	4,347	4,810	5,271	5,730	6,188	6,645
20					4,284	4,797	5,308	5,817	6,324	6,829	7,333
21					4,705	5,268	5,830	6,388	6,945	7,501	8,054
22					5,145	5,761	6,375	6,986	7,595	8,202	8,807
23						6,275	6,943	7,609	8,272	8,933	9,592
24						6,809	7,534	8,257	8,977	9,694	10,410
25						7,365	8,149	8,931	9,709	10,485	11,259
26							8,787	9,630	10,469	11,306	12,140
27							9,448	10,354	11,256	12,156	13,053
28							10,132	11,103	12,071	13,036	13,998

continued

Table 11.--Predicted weight of total tree wood and bark for yellow-poplar trees [1/] (continued)

D.b.h.	Total tree height (feet) [2/]										
(inches)	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	DRY [4/]										
6	93	116	140	163	187						
7	127	159	191	223	255	287					
8	166	208	250	292	334	376	418				
9		263	317	370	423	477	530	584			
10			392	458	524	590	656	722	788		
11			475	555	635	715	795	875	956		
12			566	661	757	852	948	1,044	1,139	1,235	
13			665	777	889	1,002	1,114	1,227	1,339	1,452	
14				903	1,033	1,163	1,294	1,425	1,555	1,686	1,817
15				1,038	1,187	1,337	1,487	1,638	1,788	1,939	2,089
16				1,182	1,353	1,523	1,694	1,866	2,037	2,208	2,380
17				1,336	1,529	1,722	1,915	2,109	2,302	2,496	2,690
18				1,499	1,716	1,932	2,149	2,366	2,584	2,801	3,019
19					1,914	2,155	2,397	2,639	2,882	3,124	3,367
20					2,123	2,391	2,659	2,928	3,196	3,465	3,735
21					2,342	2,638	2,934	3,231	3,527	3,824	4,121
22					2,573	2,898	3,223	3,549	3,875	4,201	4,527
23						3,170	3,526	3,882	4,239	4,595	4,952
24						3,455	3,842	4,230	4,619	5,008	5,397
25						3,751	4,172	4,594	5,016	5,438	5,860
26							4,516	4,973	5,429	5,886	6,343
27							4,874	5,366	5,859	6,352	6,846
28							5,245	5,775	6,306	6,836	7,367

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -0.69614 + 0.96067\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -1.22162 + 1.00963\ \text{Log}_{10}\ (D^2Th)$.

Table 12.--Predicted weight of all aboveground wood excluding bark for yellow-poplar trees [1/]

D.b.h. (inches)	Total tree height (feet) [2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	GREEN [3/]										
6	173	215	257	299	340						
7	234	291	347	403	459	515					
8	303	377	450	523	595	668	740				
9		474	566	657	749	840	930	1,021			
10			695	807	919	1,031	1,142	1,253	1,363		
11			836	972	1,106	1,241	1,375	1,508	1,641		
12			990	1,151	1,310	1,469	1,628	1,786	1,944	2,101	
13			1,157	1,345	1,531	1,717	1,902	2,087	2,272	2,456	
14				1,553	1,769	1,983	2,197	2,411	2,624	2,836	3,048
15				1,776	2,023	2,268	2,513	2,757	3,001	3,244	3,486
16				2,014	2,293	2,572	2,849	3,126	3,402	3,678	3,953
17				2,266	2,581	2,894	3,206	3,518	3,828	4,138	4,448
18				2,533	2,884	3,234	3,583	3,931	4,279	4,625	4,971
19					3,204	3,593	3,981	4,368	4,753	5,138	5,522
20					3,540	3,970	4,399	4,826	5,252	5,678	6,102
21					3,893	4,365	4,837	5,306	5,775	6,243	6,710
22					4,262	4,779	5,295	5,809	6,322	6,834	7,345
23						5,211	5,773	6,334	6,893	7,452	8,009
24						5,661	6,271	6,881	7,489	8,095	8,700
25						6,128	6,790	7,450	8,103	8,764	9,419
26							7,328	8,040	8,751	9,459	10,166
27							7,887	8,653	9,417	10,180	10,941
28							8,465	9,287	10,103	10,926	11,743

continued

Table 12.--Predicted weight of all aboveground wood excluding bark for yellow-poplar trees[1/] (continued)

D.b.h.	Total tree height (feet)[2/]										
(inches)	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	DRY [4/]										
6	77	97	117	136	156						
7	106	133	159	186	213	240					
8	139	174	209	244	280	315	351				
9		221	265	310	355	400	445	490			
10			329	384	440	495	551	607	663		
11			398	466	533	601	669	736	804		
12			475	556	636	717	798	879	959	1,041	
13			559	654	748	843	938	1,033	1,128	1,224	
14				759	870	980	1,090	1,201	1,311	1,422	1,533
15				873	1,000	1,127	1,254	1,381	1,508	1,636	1,763
16				996	1,140	1,284	1,429	1,574	1,719	1,864	2,009
17				1,126	1,289	1,452	1,616	1,780	1,944	2,108	2,272
18				1,264	1,447	1,630	1,814	1,998	2,182	2,367	2,551
19					1,615	1,819	2,024	2,229	2,435	2,641	2,847
20					1,791	2,019	2,246	2,474	2,702	2,930	3,158
21					1,978	2,228	2,479	2,731	2,983	3,235	3,487
22					2,173	2,449	2,725	3,001	3,277	3,554	3,831
23						2,679	2,981	3,284	3,586	3,889	4,193
24						2,921	3,250	3,579	3,909	4,240	4,570
25						3,173	3,530	3,888	4,247	4,605	4,965
26							3,822	4,210	4,598	4,986	5,375
27							4,126	4,544	4,963	5,383	5,802
28							4,442	4,892	5,343	5,794	6,246

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -0.83371 + 0.97283\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -1.31186 + 1.01330\ \text{Log}_{10}\ (D^2Th)$.

Table 13.--Predicted weight of wood and bark in main stem to saw-log merchantable top for yellow-poplar trees[1/]

D.b.h. (inches)	Total tree height (feet)[2/]								
	60	70	80	90	100	110	120	130	140
	Pounds								
	GREEN[3/]								
12	780	923	1,068	1,214	1,362	1,511	1,662	1,814	
13	929	1,099	1,272	1,446	1,622	1,800	1,979	2,160	
14		1,292	1,495	1,700	1,907	2,116	2,327	2,539	2,753
15		1,502	1,738	1,976	2,217	2,460	2,705	2,952	3,201
16		1,729	2,001	2,275	2,552	2,832	3,114	3,398	3,685
17		1,974	2,284	2,597	2,913	3,233	3,555	3,879	4,206
18		2,236	2,587	2,942	3,300	3,662	4,027	4,395	4,765
19			2,911	3,310	3,714	4,121	4,531	4,945	5,362
20			3,256	3,703	4,154	4,609	5,068	5,531	5,997
21			3,622	4,119	4,621	5,127	5,638	6,153	6,671
22			4,009	4,559	5,114	5,675	6,240	6,810	7,384
23				5,023	5,636	6,253	6,876	7,504	8,136
24				5,512	6,184	6,862	7,546	8,234	8,928
25				6,026	6,760	7,502	8,249	9,002	9,760
26					7,365	8,172	8,986	9,806	10,632
27					7,997	8,874	9,758	10,648	11,545
28					8,658	9,607	10,564	11,528	12,499

continued

Table 13.--Predicted weight of wood and bark in main stem to saw-log merchantable top for yellow-poplar trees[1/] (continued)

D.b.h. (inches)	Total tree height (feet)[2/]								
	60	70	80	90	100	110	120	130	140
	Pounds								
	DRY[4/]								
12	365	435	506	579	653	728	804	881	
13	438	522	608	695	784	874	965	1,057	
14		618	720	823	928	1,035	1,143	1,252	1,362
15		723	842	963	1,086	1,211	1,337	1,465	1,595
16		838	976	1,116	1,259	1,403	1,550	1,698	1,847
17		962	1,121	1,282	1,445	1,611	1,779	1,949	2,121
18		1,096	1,277	1,460	1,647	1,836	2,027	2,221	2,417
19			1,444	1,652	1,863	2,077	2,293	2,513	2,734
20			1,623	1,857	2,094	2,334	2,578	2,824	3,073
21			1,815	2,075	2,340	2,609	2,881	3,157	3,435
22			2,018	2,308	2,602	2,901	3,204	3,510	3,820
23				2,554	2,880	3,211	3,546	3,885	4,228
24				2,814	3,174	3,538	3,907	4,281	4,659
25				3,089	3,484	3,884	4,289	4,699	5,113
26					3,810	4,247	4,690	5,139	5,592
27					4,152	4,629	5,112	5,601	6,094
28					4,511	5,029	5,554	6,085	6,622

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -1.40405 + 1.09136\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -1.92791 + 1.14055\ \text{Log}_{10}\ (D^2Th)$.

Table 14.--Predicting weight of wood excluding bark in main stem to saw-log merchantable top for yellow-poplar trees [1/]

D.b.h. (inches)	Total tree height (feet) [2/]								
	60	70	80	90	100	110	120	130	140
	Pounds								
	GREEN [3/]								
12	645	765	886	1,009	1,134	1,260	1,387	1,516	
13	770	913	1,058	1,205	1,354	1,504	1,656	1,809	
14		1,075	1,246	1,419	1,595	1,772	1,950	2,131	2,313
15		1,252	1,451	1,653	1,857	2,064	2,272	2,482	2,694
16		1,444	1,674	1,907	2,142	2,380	2,620	2,863	3,107
17		1,651	1,914	2,180	2,449	2,721	2,996	3,273	3,552
18		1,874	2,172	2,474	2,779	3,088	3,399	3,714	4,031
19			2,447	2,788	3,132	3,480	3,831	4,185	4,543
20			2,741	3,122	3,508	3,898	4,291	4,688	5,088
21			3,053	3,478	3,907	4,341	4,780	5,222	5,667
22			3,384	3,854	4,331	4,812	5,297	5,787	6,281
23				4,252	4,778	5,308	5,844	6,385	6,930
24				4,672	5,249	5,832	6,421	7,015	7,613
25				5,113	5,745	6,383	7,027	7,677	8,332
26					6,265	6,961	7,664	8,372	9,087
27					6,810	7,567	8,330	9,101	9,878
28					7,380	8,200	9,028	9,863	10,705

continued

Table 14.--Predicting weight of wood excluding bark in main stem to saw-log merchantable top for yellow-poplar trees [1/] (continued)

D.b.h. (inches)	Total tree height (feet) [2/]								
	60	70	80	90	100	110	120	130	140
	Pounds								
	DRY [4/]								
12	303	362	423	484	547	611	676	742	
13	365	436	509	583	659	736	814	893	
14		517	604	692	782	873	966	1,060	1,155
15		607	709	812	917	1,025	1,133	1,243	1,355
16		705	823	943	1,065	1,190	1,316	1,444	1,573
17		811	947	1,085	1,226	1,369	1,514	1,661	1,810
18		926	1,081	1,239	1,399	1,563	1,728	1,896	2,066
19			1,225	1,404	1,586	1,771	1,959	2,149	2,342
20			1,379	1,581	1,786	1,995	2,206	2,420	2,637
21			1,544	1,770	2,000	2,233	2,470	2,710	2,952
22			1,720	1,971	2,227	2,487	2,751	3,018	3,288
23				2,185	2,469	2,757	3,049	3,345	3,645
24				2,412	2,724	3,042	3,365	3,691	4,022
25				2,651	2,994	3,344	3,698	4,057	4,421
26					3,279	3,662	4,050	4,443	4,841
27					3,579	3,996	4,420	4,849	5,283
28					3,893	4,347	4,808	5,275	5,748

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -1.54143 + 1.10526\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -2.07644 + 1.15782\ \text{Log}_{10}\ (D^2Th)$.

Table 15.--Predicted weight of wood and bark in main stem to 2-inch d.i.b. top for yellow-poplar trees [1/]

D.b.h.	Total tree height (feet) [2/]										
(inches)	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	GREEN [3/]										
6	187	232	277	322	367						
7	252	314	375	436	496	557					
8	327	407	486	565	644	723	801				
9		512	612	712	811	910	1,008	1,107			
10			752	874	996	1,118	1,239	1,360	1,480		
11			906	1,053	1,200	1,346	1,492	1,638	1,783		
12			1,074	1,249	1,423	1,596	1,769	1,942	2,114	2,286	
13			1,256	1,460	1,663	1,866	2,068	2,270	2,472	2,673	
14				1,687	1,922	2,157	2,391	2,624	2,857	3,089	3,321
15				1,931	2,200	2,468	2,736	3,003	3,269	3,535	3,800
16				2,190	2,496	2,800	3,103	3,406	3,709	4,010	4,311
17				2,466	2,809	3,152	3,494	3,835	4,175	4,514	4,853
18				2,757	3,141	3,524	3,907	4,288	4,668	5,048	5,427
19					3,491	3,917	4,342	4,765	5,188	5,610	6,032
20					3,859	4,330	4,799	5,268	5,735	6,202	6,667
21					4,245	4,763	5,280	5,795	6,309	6,822	7,334
22					4,649	5,216	5,782	6,346	6,909	7,471	8,032
23						5,690	6,307	6,922	7,536	8,149	8,761
24						6,183	6,853	7,522	8,190	8,856	9,521
25						6,696	7,422	8,147	8,870	9,591	10,311
26							8,014	8,796	9,576	10,355	11,132
27							8,627	9,469	10,309	11,147	11,984
28							9,262	10,166	11,068	11,968	12,867

continued

Table 15.--Predicted weight of wood and bark in main stem to 2-inch d.i.b. top for yellow-poplar trees[1/] (continued)

D.b.h. (inches)	Total tree height (feet)[2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	DRY[4/]										
6	81	101	122	143	164						
7	111	139	168	196	225	254					
8	146	183	221	258	296	334	372				
9		233	281	329	377	425	474	523			
10			348	408	468	528	588	648	709		
11			424	496	569	642	715	788	862		
12			506	593	680	767	855	942	1,030	1,118	
13			597	699	801	904	1,007	1,110	1,214	1,318	
14				813	933	1,052	1,172	1,293	1,413	1,534	1,655
15				937	1,074	1,212	1,350	1,489	1,628	1,767	1,906
16				1,069	1,226	1,384	1,541	1,699	1,858	2,017	2,176
17				1,211	1,388	1,567	1,745	1,924	2,104	2,284	2,464
18				1,361	1,561	1,761	1,962	2,164	2,365	2,568	2,770
19					1,744	1,968	2,192	2,417	2,643	2,868	3,095
20					1,937	2,186	2,435	2,685	2,936	3,187	3,438
21					2,141	2,416	2,691	2,968	3,244	3,522	3,800
22					2,355	2,658	2,961	3,264	3,569	3,874	4,180
23						2,911	3,243	3,576	3,909	4,244	4,579
24						3,176	3,539	3,902	4,266	4,630	4,996
25						3,454	3,848	4,242	4,638	5,035	5,432
26							4,170	4,598	5,026	5,456	5,887
27							4,505	4,967	5,431	5,895	6,360
28							4,854	5,352	5,851	6,351	6,852

1/ Blocked-in area indicates range of data.
2/ Includes 1-foot stump allowance.
3/ $\text{Log}_{10} Y = -0.081474 + 0.97694 \text{ Log}_{10} (D^2Th)$.
4/ $\text{Log}_{10} Y = -1.33025 + 1.02493 \text{ Log}_{10} (D^2Th)$.

Table 16.--Predicted weight of wood excluding bark in main stem to 2-inch d.i.b. top for yellow-poplar trees [1/]

D.b.h. (inches)	Total tree height (feet) [2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	GREEN [3/]										
6	153	191	228	265	303						
7	207	258	309	360	410	461					
8	270	336	402	468	534	599	665				
9		424	507	590	673	756	839	921			
10			624	726	829	931	1,032	1,134	1,235		
11			753	877	1,000	1,123	1,246	1,368	1,491		
12			894	1,040	1,187	1,333	1,479	1,624	1,770	1,915	
13			1,047	1,218	1,390	1,561	1,731	1,902	2,072	2,242	
14				1,410	1,608	1,806	2,003	2,201	2,398	2,595	2,791
15				1,615	1,842	2,069	2,295	2,521	2,747	2,972	3,198
16				1,834	2,092	2,350	2,607	2,863	3,120	3,376	3,631
17				2,067	2,358	2,648	2,937	3,227	3,515	3,804	4,092
18				2,313	2,639	2,963	3,288	3,611	3,935	4,257	4,580
19					2,935	3,297	3,657	4,017	4,377	4,736	5,095
20					3,248	3,647	4,046	4,445	4,842	5,240	5,637
21					3,575	4,015	4,455	4,893	5,331	5,769	6,206
22					3,919	4,401	4,882	5,363	5,843	6,323	6,801
23						4,804	5,329	5,854	6,378	6,901	7,424
24						5,224	5,795	6,366	6,936	7,505	8,074
25						5,662	6,281	6,899	7,517	8,134	8,750
26							6,786	7,454	8,121	8,787	9,453
27							7,310	8,029	8,748	9,466	10,183
28							7,853	8,626	9,398	10,169	10,940

continued

Table 16.--Predicted weight of wood excluding bark in main stem to 2-inch d.i.b. top for yellow-poplar trees [1/] (continued)

D.b.h. (inches)	Total tree height (feet) [2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	DRY [4/]										
6	68	85	103	121	138						
7	93	117	141	166	190	214					
8	122	154	186	218	250	282	315				
9		196	237	278	319	360	401	442			
10			294	345	396	447	498	549	601		
11			358	420	482	544	606	668	731		
12			428	502	576	650	725	799	874	949	
13			505	592	679	767	855	943	1,031	1,119	
14				690	791	893	995	1,098	1,201	1,304	1,407
15				795	912	1,029	1,147	1,265	1,384	1,503	1,622
16				908	1,041	1,176	1,310	1,445	1,581	1,716	1,852
17				1,028	1,180	1,332	1,484	1,637	1,791	1,945	2,099
18				1,157	1,327	1,498	1,670	1,842	2,014	2,187	2,361
19					1,483	1,674	1,866	2,059	2,252	2,445	2,639
20					1,649	1,861	2,074	2,288	2,502	2,717	2,932
21					1,823	2,058	2,293	2,530	2,767	3,004	3,242
22					2,006	2,264	2,524	2,784	3,045	3,306	3,568
23						2,481	2,766	3,051	3,336	3,623	3,910
24						2,709	3,019	3,330	3,642	3,955	4,268
25						2,946	3,283	3,622	3,961	4,301	4,642
26							3,559	3,926	4,294	4,663	5,033
27							3,847	4,244	4,641	5,040	5,439
28							4,146	4,573	5,002	5,431	5,862

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -0.92750 + 0.98533\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -1.41983 + 1.02925\ \text{Log}_{10}\ (D^2Th)$.

Table 17.--Predicted weight of wood and bark in branches for yellow-poplar trees [1/]

D.b.h. (inches)	Total tree height (feet) [2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	GREEN [3/]										
6	31	37	43	49	55						
7	40	48	56	63	71	78					
8	49	60	69	79	88	98	107				
9		73	85	96	108	119	130	141			
10			101	115	128	142	155	168	180		
11			118	135	151	166	182	197	211		
12			137	156	174	192	210	227	245	261	
13			157	178	199	220	240	260	280	299	
14				202	225	249	272	294	317	338	360
15				226	253	279	305	330	355	380	404
16				252	282	311	340	368	396	423	450
17				279	312	344	376	407	438	468	498
18				307	343	379	414	448	482	515	548
19					376	415	453	491	528	564	600
20					409	452	494	535	575	615	654
21					444	490	536	580	624	667	710
22					480	530	579	627	674	721	767
23						571	624	675	726	777	826
24						613	670	725	780	834	887
25						656	717	776	835	893	950
26							766	829	892	953	1,014
27							815	883	950	1,016	1,081
28							867	939	1,009	1,079	1,148

Table 17.--Predicted weight of wood and bark in branches for yellow-poplar trees [1/] (continued)

D.b.h. (inches)	Total tree height (feet) [2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	DRY [4/]										
6	12	14	17	19	21						
7	15	19	22	25	28	31					
8	19	24	28	32	36	40	43				
9		29	34	39	44	49	53	58			
10			41	47	53	59	64	70	76		
11			49	56	63	69	76	83	89		
12			57	65	73	81	89	97	104	112	
13			65	75	84	93	102	111	120	129	
14				85	96	106	116	127	137	147	157
15				96	108	120	132	143	155	166	177
16				108	121	134	147	160	173	186	198
17				120	135	150	164	178	193	207	221
18				132	149	165	181	197	213	229	244
19					164	182	200	217	234	252	269
20					179	199	219	238	257	275	294
21					196	217	238	259	280	300	320
22					212	236	258	281	304	326	348
23						255	280	304	328	352	376
24						275	301	328	354	380	405
25						295	324	352	380	408	436
26							347	377	408	437	467
27							371	403	436	467	499
28							395	430	464	498	532

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -1.15689 + 0.83663\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -1.71827 + 0.88172\ \text{Log}_{10}\ (D^2Th)$.

Table 18.--Predicted weight of wood excluding bark in branches for yellow-poplar trees [1/]

D.b.h. (inches)	Total tree height (feet) [2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	GREEN [3/]										
6	20	24	28	32	36						
7	26	31	37	42	47	52					
8	32	39	46	52	59	65	71				
9		48	56	64	72	79	87	94			
10			67	77	86	95	104	113	121		
11			79	90	101	112	122	133	143		
12			92	105	117	130	142	154	166	178	
13			105	120	134	149	163	177	190	204	
14				136	153	169	185	200	216	231	246
15				153	172	190	208	225	243	260	277
16				171	192	212	232	252	271	290	309
17				190	213	235	257	279	301	322	343
18				209	234	259	284	308	332	355	378
19					257	284	311	338	364	389	415
20					281	310	340	368	397	425	453
21					305	337	369	401	431	462	492
22					330	365	400	434	467	500	533
23						394	431	468	504	540	575
24						424	464	503	542	580	618
25						455	497	540	581	622	663
26							532	577	621	665	709
27							567	615	663	710	756
28							604	655	705	755	805

continued

Table 18.--Predicted weight of wood excluding bark in branches for yellow-poplar trees[1/] (continued)

D.b.h.	Total tree height (feet)[2/]										
(inches)	40	50	60	70	80	90	100	110	120	130	140
	Pounds										
	DRY[4/]										
6	9	11	13	15	17						
7	12	15	17	20	22	25					
8	15	19	22	25	28	31	34				
9		23	27	31	35	38	42	46			
10			32	37	41	46	50	55	59		
11			38	44	49	54	59	64	69		
12			44	51	57	63	69	75	81	87	
13			51	58	65	72	79	86	93	99	
14				66	74	82	90	98	105	113	121
15				75	84	93	102	110	119	127	136
16				83	94	104	114	123	133	142	152
17				93	104	115	126	137	148	158	169
18				102	115	127	139	151	163	175	186
19					126	140	153	166	179	192	205
20					138	153	167	181	196	210	224
21					150	166	182	197	213	228	243
22					162	180	197	214	231	247	264
23						194	213	231	249	267	285
24						209	229	249	268	288	307
25						225	246	267	288	309	329
26							263	286	308	330	352
27							281	305	329	353	376
28							299	325	351	376	401

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -1.40010 + 0.85422\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -1.76294 + 0.86612\ \text{Log}_{10}\ (D^2Th)$.

Table 19.--Predicted green volume of total tree wood and bark for yellow-poplar trees [1/]

D.b.h.	Total tree height (feet) [2/]										
(inches)	40	50	60	70	80	90	100	110	120	130	140
	Cubic feet										
	WOOD [3/]										
6	3.2	4.0	4.8	5.6	6.4						
7	4.4	5.5	6.6	7.6	8.7	9.8					
8	5.7	7.1	8.5	9.9	11.3	12.7	14.1				
9		9.0	10.8	12.5	14.3	16.1	17.8	19.6			
10			13.3	15.4	17.6	19.8	21.9	24.1	26.3		
11			16.0	18.6	21.2	23.9	26.5	29.1	31.7		
12			19.0	22.1	25.2	28.3	31.5	34.6	37.7	40.8	
13			22.2	25.9	29.6	33.2	36.8	40.5	44.1	47.7	
14				30.0	34.2	38.4	42.6	46.9	51.1	55.3	59.4
15				34.4	39.2	44.0	48.9	53.7	58.5	63.3	68.1
16				39.0	44.5	50.0	55.5	61.0	66.5	71.9	77.4
17				44.0	50.2	56.4	62.6	68.7	74.9	81.1	87.2
18				49.3	56.2	63.1	70.0	77.0	83.9	90.8	97.6
19					62.5	70.2	77.9	85.6	93.3	101.0	108.7
20					69.2	77.7	86.2	94.8	103.3	111.8	120.2
21					76.2	85.6	95.0	104.3	113.7	123.1	132.4
22					83.5	93.8	104.1	114.4	124.6	134.9	145.1
23						102.4	113.7	124.9	136.1	147.3	158.5
24						111.4	123.6	135.8	148.0	160.2	172.3
25						120.8	134.0	147.2	160.4	173.6	186.8
26							144.8	159.1	173.4	187.6	201.9
27							156.0	171.4	186.8	202.1	217.5
28							167.6	184.2	200.7	217.2	233.7

continued

Table 19.--Predicted green volume of total tree wood and bark for yellow-poplar trees [1] (continued)

D.b.h.	Total tree weight (feet)[2]										
(inches)	40	50	60	70	80	90	100	110	120	130	140
	Cubic feet										
	WOOD AND BARK [4]										
6	4.0	4.9	5.9	6.9	7.9						
7	5.4	6.7	8.0	9.4	10.7	12.0					
8	7.0	8.8	10.5	12.2	14.0	15.7	17.4				
9		11.1	13.3	15.4	17.6	19.8	22.0	24.2			
10			16.3	19.0	21.7	24.4	27.1	29.8	32.5		
11			19.7	23.0	26.3	29.5	32.8	36.0	39.3		
12			23.5	27.3	31.2	35.1	38.9	42.8	46.6	50.5	
13			27.5	32.0	36.6	41.1	45.6	50.2	54.7	59.2	
14				37.1	42.4	47.6	52.9	58.1	63.3	68.6	73.8
15				42.5	48.6	54.6	60.6	66.6	72.6	78.6	84.6
16				48.4	55.2	62.1	68.9	75.7	82.6	89.4	96.2
17				54.5	62.3	70.0	77.7	85.4	93.1	100.8	108.5
18				61.1	69.8	78.4	87.0	95.7	104.3	112.9	121.5
19					77.6	87.3	96.9	106.5	116.1	125.7	135.3
20					86.0	96.6	107.3	117.9	128.5	139.2	149.8
21					94.7	106.4	118.2	129.9	141.6	153.3	165.0
22					103.9	116.7	129.6	142.5	155.3	168.1	181.0
23						127.5	141.6	155.6	169.6	183.6	197.7
24						138.7	154.0	169.3	184.6	199.8	215.1
25						150.5	167.0	183.6	200.1	216.7	233.2
26							180.5	198.5	216.3	234.2	252.1
27							194.6	213.9	233.2	252.4	271.7
28							209.1	229.9	250.6	271.3	292.0

[1] Blocked-in area indicates range of data.
[2] Includes 1-foot stump allowance.
[3] $\text{Log}_{10}\ Y = -2.60833 + 0.98740\ \text{Log}_{10}\ (D^2Th)$.
[4] $\text{Log}_{10}\ Y = -2.53544 + 0.99215\ \text{Log}_{10}\ (D^2Th)$.

Table 20.--Predicted green volume of wood and bark in main stem to saw-log merchantable top for yellow-poplar trees[1/]

D.b.h. (inches)	Total tree height (feet)[2/]								
	60	70	80	90	100	110	120	130	140
	Cubic feet								
	WOOD[3/]								
12	12.2	14.6	16.9	19.3	21.8	24.3	26.8	29.3	
13	14.7	17.4	20.3	23.2	26.1	29.1	32.1	35.2	
14		20.6	24.0	27.4	30.9	34.4	38.0	41.6	45.2
15		24.1	28.1	32.1	36.1	40.2	44.4	48.6	52.9
16		27.9	32.5	37.1	41.8	46.6	51.4	56.2	61.2
17		32.0	37.2	42.6	47.9	53.4	58.9	64.5	70.2
18		36.4	42.4	48.4	54.6	60.8	67.1	73.4	79.9
19			47.9	54.7	61.7	68.7	75.8	83.0	90.2
20			53.8	61.5	69.3	77.1	85.1	93.2	101.4
21			60.1	68.7	77.3	86.2	95.1	104.1	113.2
22			66.8	76.3	85.9	95.7	105.6	115.6	125.8
23				84.3	95.0	105.9	116.8	127.9	139.1
24				92.9	104.6	116.6	128.6	140.8	153.1
25				101.9	114.8	127.8	141.1	154.4	168.0
26					125.4	139.7	154.2	168.8	183.5
27					136.6	152.2	167.9	183.8	199.9
28					148.3	165.2	182.3	199.6	217.1

continued

Table 20.--Predicted green volume of wood and bark in main stem to saw-log merchantable top for yellow-poplar trees [1/] (continued)

D.b.h. (inches)	Total tree height (feet)[2/]								
	60	70	80	90	100	110	120	130	140
	Cubic feet								
	WOOD AND BARK [4/]								
12	15.5	18.4	21.3	24.3	27.3	30.4	33.5	36.6	
13	18.5	22.0	25.5	29.0	32.7	36.3	40.0	43.7	
14		25.9	30.0	34.2	38.5	42.8	47.2	51.6	56.0
15		30.2	35.0	39.9	44.9	49.9	55.0	60.1	65.3
16		34.9	40.4	46.1	51.8	57.6	63.5	69.4	75.4
17		39.9	46.3	52.8	59.3	66.0	72.7	79.5	86.3
18		45.3	52.6	59.9	67.4	74.9	82.6	90.2	98.0
19			59.3	67.6	76.0	84.5	93.1	101.8	110.5
20			66.5	75.8	85.2	94.7	104.4	114.1	123.9
21			74.1	84.5	95.0	105.6	116.4	127.2	138.1
22			82.2	93.7	105.3	117.1	129.1	141.1	153.2
23				103.4	116.3	129.3	142.5	155.8	169.2
24				113.7	127.9	142.2	156.6	171.2	186.0
25				124.5	140.0	155.7	171.5	187.5	203.7
26					152.8	169.9	187.2	204.6	222.2
27					166.2	184.8	203.6	222.6	241.7
28					180.2	200.4	220.8	241.4	262.1

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -3.36739 + 1.13164\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -3.19278 + 1.11325\ \text{Log}_{10}\ (D^2Th)$.

Table 21.--Predicted green volume of wood and bark in main stem to 2-inch d.i.b. top for yellow-poplar trees[1/]

D.b.h. (inches)	Total tree height (feet)[2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Cubic feet										
	WOOD[3/]										
6	2.9	3.6	4.3	5.0	5.7						
7	3.9	4.9	5.8	6.8	7.8	8.8					
8	5.1	6.4	7.6	8.9	10.2	11.5	12.7				
9		8.0	9.7	11.3	12.9	14.5	16.1	17.7			
10			11.9	13.9	15.9	17.9	19.9	21.9	23.9		
11			14.4	16.9	19.3	21.7	24.1	26.5	28.9		
12			17.2	20.1	22.9	25.8	28.7	31.6	34.4	37.3	
13			20.2	23.6	26.9	30.3	33.7	37.1	40.4	43.8	
14				27.3	31.2	35.2	39.1	43.0	46.9	50.8	54.7
15				31.4	35.9	40.4	44.9	49.4	53.9	58.4	62.9
16				35.7	40.8	45.9	51.1	56.2	61.3	66.4	71.5
17				40.3	46.1	51.9	57.7	63.4	69.2	75.0	80.8
18				45.2	51.7	58.2	64.7	71.1	77.6	84.1	90.6
19					57.6	64.8	72.1	79.3	86.5	93.7	100.9
20					63.9	71.9	79.9	87.9	95.9	103.9	111.9
21					70.4	79.2	88.1	96.9	105.7	114.5	123.4
22					77.3	87.0	96.7	106.3	116.0	125.7	135.4
23						95.1	105.7	116.3	126.9	137.4	148.0
24						103.5	115.1	126.6	138.1	149.7	161.2
25						112.4	124.9	137.4	149.9	162.4	175.0
26							135.1	148.6	162.2	175.7	189.3
27							145.7	160.3	174.9	189.5	204.1
28							156.7	172.4	188.2	203.9	219.6

continued

Table 21.--Predicted green volume of wood and bark in main stem to 2-inch d.i.b. top for yellow-poplar trees [1/] (continued)

D.b.h. (inches)	Total tree height (feet) [2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Cubic feet										
	WOOD AND BARK [4/]										
6	3.4	4.3	5.1	6.0	6.9						
7	4.7	5.8	7.0	8.2	9.4	10.6					
8	6.1	7.6	9.2	10.7	12.3	13.8	15.4				
9		9.7	11.7	13.6	15.6	17.6	19.5	21.5			
10			14.4	16.9	19.3	21.7	24.2	26.6	29.1		
11			17.5	20.4	23.4	26.4	29.3	32.3	35.2		
12			20.9	24.4	27.9	31.4	35.0	38.5	42.0	45.6	
13			24.5	28.7	32.8	36.9	41.1	45.3	49.4	53.6	
14				33.3	38.1	42.9	47.7	52.6	57.4	62.2	67.1
15				38.3	43.8	49.3	54.9	60.4	66.0	71.6	77.1
16				43.6	49.9	56.2	62.5	68.9	75.2	81.5	87.9
17				49.3	56.4	63.6	70.7	77.9	85.0	92.2	99.3
18				55.3	63.3	71.3	79.4	87.4	95.4	103.5	111.5
19					70.6	79.6	88.5	97.5	106.5	115.4	124.4
20					78.4	88.3	98.2	108.1	118.1	128.0	138.0
21					86.5	97.4	108.4	119.4	130.3	141.3	152.3
22					95.0	107.0	119.1	131.1	143.2	155.3	167.3
23						117.1	130.3	143.5	156.7	169.9	183.1
24						127.6	142.0	156.4	170.7	185.1	199.5
25						138.6	154.2	169.8	185.4	201.1	216.7
26							166.9	183.8	200.7	217.7	234.6
27							180.2	198.4	216.7	234.9	253.2
28							193.9	213.6	233.2	252.9	272.5

[1/] Blocked-in area indicates range of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -2.70952 + 1.00212\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -2.66141 + 1.01119\ \text{Log}_{10}\ (D^2Th)$.

Table 22.--Predicted green volume of wood and bark in branches for yellow-poplar trees[1/]

D.b.h. (inches)	Total tree height (feet)[2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Cubic feet										
	WOOD [3/]										
6	0.4	0.5	0.5	0.6	0.7						
7	.5	.6	.7	.8	.9	1.0					
8	.6	.7	.9	1.0	1.1	1.2	1.3				
9		.9	1.0	1.2	1.3	1.5	1.6	1.7			
10			1.2	1.4	1.6	1.8	1.9	2.1	2.2		
11			1.5	1.7	1.9	2.1	2.3	2.4	2.6		
12			1.7	1.9	2.2	2.4	2.6	2.8	3.1	3.3	
13			1.9	2.2	2.5	2.7	3.0	3.2	3.5	3.7	
14				2.5	2.8	3.1	3.4	3.7	4.0	4.2	4.5
15				2.8	3.2	3.5	3.8	4.1	4.4	4.8	5.1
16				3.1	3.5	3.9	4.3	4.6	5.0	5.3	5.6
17				3.5	3.9	4.3	4.7	5.1	5.5	5.9	6.3
18				3.8	4.3	4.7	5.2	5.6	6.1	6.5	6.9
19					4.7	5.2	5.7	6.2	6.6	7.1	7.6
20					5.1	5.7	6.2	6.7	7.2	7.7	8.2
21					5.6	6.2	6.7	7.3	7.9	8.4	8.9
22					6.0	6.7	7.3	7.9	8.5	9.1	9.7
23						7.2	7.8	8.5	9.2	9.8	10.4
24						7.7	8.4	9.1	9.8	10.5	11.2
25						8.3	9.0	9.8	10.5	11.3	12.0
26							9.7	10.5	11.3	12.1	12.8
27							10.3	11.2	12.0	12.8	13.7
28							10.9	11.9	12.8	13.7	14.5

continued

Table 22.--Predicted green volume of wood and bark in branches for yellow-poplar trees[1/] (continued)

D.b.h. (inches)	Total tree height (feet) [2/]										
	40	50	60	70	80	90	100	110	120	130	140
	Cubic feet										
	WOOD AND BARK [4/]										
6	0.5	0.7	0.8	0.9	1.0						
7	.7	.9	1.0	1.1	1.3	1.4					
8	.9	1.1	1.2	1.4	1.6	1.7	1.9				
9		1.3	1.5	1.7	1.9	2.1	2.3	2.5			
10		1.5	1.8	2.1	2.3	2.5	2.8	3.0	3.2		
11			2.1	2.4	2.7	3.0	3.2	3.5	3.8		
12			2.4	2.8	3.1	3.4	3.8	4.1	4.4	4.7	
13			2.8	3.2	3.6	3.9	4.3	4.6	5.0	5.3	
14				3.6	4.0	4.4	4.9	5.3	5.7	6.1	6.4
15				4.0	4.5	5.0	5.5	5.9	6.4	6.8	7.2
16				4.5	5.0	5.6	6.1	6.6	7.1	7.6	8.1
17				5.0	5.6	6.2	6.7	7.3	7.8	8.4	8.9
18				5.5	6.1	6.8	7.4	8.0	8.6	9.2	9.8
19					6.7	7.4	8.1	8.8	9.4	10.1	10.7
20					7.3	8.1	8.8	9.6	10.3	11.0	11.7
21					7.9	8.8	9.6	10.4	11.2	11.9	12.7
22					8.6	9.5	10.4	11.2	12.1	12.9	13.7
23						10.2	11.2	12.1	13.0	13.9	14.8
24						11.0	12.0	13.0	13.9	14.9	15.9
25						11.7	12.8	13.9	14.9	16.0	17.0
26							13.7	14.8	15.9	17.1	18.1
27							14.6	15.8	17.0	18.2	19.3
28							15.5	16.8	18.1	19.3	20.5

[1/] Blocked-in area indicates ranges of data.
[2/] Includes 1-foot stump allowance.
[3/] $\text{Log}_{10}\ Y = -3.09526 + 0.84474\ \text{Log}_{10}\ (D^2Th)$.
[4/] $\text{Log}_{10}\ Y = -2.90517 + 0.83679\ \text{Log}_{10}\ (D^2Th)$.

Clark, Alexander, III, and James G. Schroeder
1977. Biomass of yellow-poplar in natural stands in western North Carolina. USDA For. Serv. Res. Pap. SE-165, 41 p. Southeast. For. Exp. Stn., Asheville, N. C.

Aboveground biomass was determined for yellow-poplar (Liriodendron tulipifera L.) trees 6 to 28 inches d.b.h. growing in natural, uneven-aged mountain cove stands in western North Carolina. Specific gravity, moisture content, and green weight per cubic foot are presented for the total tree and its components. Tables developed from regression equations show weight and volume of the total tree and its components by d.b.h. and total height class.

Keywords: Biomass, component proportions, Liriodendron tulipifera L., prediction equations, volume, weight.

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